

THÈSE DE DOCTORAT

de l'Université de recherche Paris Sciences et Lettres
PSL Research University

Préparée à l'Université Paris-Dauphine

Facing threats by sharing information for renewable natural
resources management

École Doctorale de Dauphine — ED 543

Spécialité **Informatique**

**Soutenue le 03.10.2016
par Nicolas PAGET**

Dirigée par **Dr. Alexis TSOUKIÀS**

Dr. Olivier BARRETEAU

COMPOSITION DU JURY :

Dr. Alexis DROGOUL
IRD
Rapporteur

Prof. Anthony JAKEMAN
iCAM, Fenner School, ANU
Rapporteur

Dr. Cyril TISSOT
CNRS
Rapporteur

Dr. Pascale ZARATE
IRIT
Membre du jury

Dr. Alexis TSOUKIÀS
LAMSADE
Directeur de thèse

Dr. Olivier BARRETEAU
IRSTEA
Co-Directeur de thèse

Abstract

This thesis aims at exploring the link between information sharing and collective natural resources management (NRM). Reflexivity is often referred to as a possible solution and one of the main ways to mobilize actors around collective objects. This reflexivity may be achieved through the implementation and use of information sharing artifacts.

So as to qualify the relation linking information sharing and NRM, I focused on the specific case of oyster farmers, investigating two case studies: the Thau Basin, France, and several estuaries in New South Wales, Australia. Oyster farmers are particularly sensitive to water quality and are currently severely harmed by a virulent virus. Locally, actors developed and used various types of information sharing artifacts. Artifacts are destined to tackle *threats* that oysters farmers face.

Realizing this focal point of interest led to develop the concept of threats using the traditional goods and resources typology as a base for comparison. Threats are defined as the $\langle \mathcal{A}, \mathcal{C}, I, \mathcal{D}, \mathcal{E} \rangle$ model: a group of actors \mathcal{A} is concerned for some characteristics \mathcal{C} of goods or resources they use which is influenced by local infrastructure I , human decisions \mathcal{D} and environmental dynamics \mathcal{E} . They are organized along two main axes: internality, that determines how open or closed the threat is, and excludability that focuses on how much actors may individually find ways to tackle the threat.

Framing oyster farming situation using this concept allows for a characterization of stakes for information sharing artifacts when they are destined to help actors cope with different types of threats, as actors of the cases do.

To explore these stakes and evaluate the role information sharing artifacts may have in social-ecological systems (SES), specifically on oyster farming, I adopted a descriptive approach and first delved into actual artifacts, evaluating qualitatively their impact with the ENCORE framework. Then, I developed an exploratory agent-based model, a tool that permits a quantitative evaluation of various facets of SESs: environment, beliefs, knowledge and practices of actors.

The various artifacts studied in the thesis show that their nature encompasses a wide variety of in goals, contents or media, may lead to improvements in reflexivity or to little to no changes. These improvements, or differences, are strongly linked to the artifact creation process.

Contents

List of Figures	v
List of Tables	vii
Acronyms	ix
Remerciements	xi
Résumé en Français	xiii
1 Introduction	1
I State of the Art	9
2 Resources, Dilemmas and SES	11
3 Threats for Goods	23
4 Information Sharing for NRM	43
Conclusion	63
II Methodology	67
Introduction	69
5 Methodology for Case Studies	71
6 Agent-Based Modeling	81
III Case Studies	95
Introduction	97

7	Estuaries, Oysters and Oyster Farming	99
8	Two Cases - SES Analysis	113
9	Goods and threats for oyster farmers	143
	Conclusion	151
IV	Results	153
	Introduction	155
10	Information Sharing for Public Threats: Microbiology	157
11	Information Sharing for Private Threats: Virus	171
V	Discussion	201
12	Discussion	203
13	Conclusion	221
	Bibliography	227
	Contents (detailed)	247
VI	Appendices	253
A	ODD protocol detailed	255
B	SES second-tier variables	259
C	Environmental Information Sharing: a Means to Support the Legitimization of Oyster Farmers' Stewardship over Wa- ter Quality Management in NSW, Australia?	261

List of Figures

1	Le cadre des Systèmes Socio-Ecologiques	xv
2	Représentation des menaces	xvi
3	Flux hydrologiques majeurs d'un bassin versant côtier	xx
4	L'information permet-elle de boucler la boucle ?	xxi
5	Principaux artéfacts étudiés	xxiii
6	La menace microbiologique sur la qualité de l'eau.	xxiv
7	La menace virale sur la vie des huîtres.	xxvii
8	Boucle principale du modèle	xxviii
2.1	Upstream - Downstream	19
2.2	Social-Ecological Systems Framework	20
3.1	Representation of threats	25
3.2	CPR management examples	31
4.1	Different steps for information	44
4.2	Forms of information	49
4.3	Interactions around threats	65
4.4	Methodologies available for research in NRM	70
5.1	Thau lagoon sheds	74
5.2	Visited estuaries in NSW	77
6.1	Schelling's segregation model	84
6.2	UML class diagram: classes	90
6.3	UML class diagram: interactions	90
6.4	UML activity and sequence diagrams	91
7.1	Coastal water flows: catchment or estuary?	101
7.2	Lagoon, estuaries, deltas	101
7.3	Microbiological influences in an estuary	105
7.4	Oyster breeding cycle	108
8.1	Oyster producing estuaries in NSW	115
8.2	Oyster production levels in NSW	116
8.3	Lower Hawkesbury oyster farming areas	118

8.4	AOC and SWOC logos	122
8.5	EMS front page and risk matrix	124
8.6	Picture of oyster farmers in an EMS	125
8.7	EMS leaflet	126
8.8	Thau basin	128
8.9	OMEGA Thau	135
9.1	Sprayed oyster shed	146
9.2	The microbiological threat	148
9.3	The virus threat	149
10.1	Threats and EMSs	159
10.2	Threats and OMEGA Thau	164
10.3	Consequences of EMS implementation	168
10.4	Consequences of OMEGA Thau implementation	168
11.1	Main classes	173
11.2	Mortality scenarios	174
11.3	Theoretical expected income	174
11.4	Main loop of the model	175
11.5	Model sequence diagram	176
11.6	Information aggregation	179
11.7	Belief update and decision-making process	181
11.8	Mortality rates	185
11.9	Quantity of oysters	185
11.10	Average size	185
11.11	Mortality rates compared to personal	187
11.12	Quantity of oysters compared to personal	187
11.13	Average size of batches compared to personal	187
11.14	Mortality rates with and without ISS	189
11.15	Quantity of oysters with and without ISS	189
11.16	Average size of batches with and without ISS	189
11.17	Cumulated mortalities and production compared to personal	191
11.18	Cumulated mortalities and production with ISS added	191
11.19	Oyster farmers beliefs	192
11.20	Distance between beliefs and virus dynamics	194
11.21	Oyster farmers mix changes	195
11.22	Oyster farmers mix choice	195
11.23	Change convergence	196
11.24	Production and convergence	197
12.1	Main loop of the model	209

List of Tables

1	Une typologie des menaces	xvii
2.1	Typology of goods and resources	13
2.2	Types of users and associated property rights	14
2.3	Prisoner's dilemma payoff matrix	15
2.4	CPR design principles	17
3.1	Elements characterizing a threat	25
3.2	Design principles and threats	29
3.3	Reinterpretation of studies as threats	30
3.4	A typology of threats	35
3.5	Good and threat examples	37
3.6	Threat variables to be added to the SES	40
4.1	Definitions of information	46
4.2	Goals for information sharing using a threat perspective	52
4.3	Types of information shared for NRM	54
4.4	Means to transfer information	55
4.5	Studies of IS in the context of NRM	60
5.1	Investigation statistics	73
6.1	ODD+D protocol	92
7.1	Oysters as resource units	106
7.2	Estuary or catchment?	110
7.3	Effects of system size choice	112
8.1	NSW Quality Assurance Program	120
8.2	Closures Thau Lagoon	130
8.3	Comparison of SESs in NSW and Thau Lagoon	137
9.1	Goods and resources for oyster farmers	144
9.2	Threats for oyster farmers	147
10.1	ENCORE applied to NSW	160

10.2	Consequences on SES in NSW	162
10.3	ENCORE applied to Thau	165
10.4	Comparison of IS artifacts	167
11.1	Networks scenarios	177
11.2	Aggregation scenarios	179
11.3	Experimental plan	183
11.4	Impacts of ISS implementation	198
12.1	Organizing a case study	206
A.1	The ODD+D protocol	256
B.1	SES variables	260

Acronyms

ABM Agent-Based Modeling.

AOC Australia's Oyster Coast.

CPR Common-pool resource.

CRCM Comité Régional de la Conchyliculture de Méditerranée.

EMS Environmental Management System.

Ifremer Institut Français de Recherche pour l'Exploitation de la Mer.

LLS Local Land Services.

NRM Natural Resources Management.

NSW New South Wales.

NSW DPI New South Wales Department of Primary Industries.

ODD Overview, Design concepts, and Details.

OISAS Oyster Industry Sustainable Aquaculture Strategy.

PO Pacific Oyster *Crassostrea Gigas*.

POMS Pacific Oyster Mortality Syndrome.

QAP Quality Assurance Programs.

SAGE Schéma d'Aménagement et de Gestion des Eaux.

SCOT Schéma de Cohérence Territoriale.

SCWO Sapphire Coast Wilderness Oysters.

SES Social-Ecological System.

SMBT Syndicat Mixte du Bassin de Thau.

SRO Sydney Rock Oyster *Saccostrea Glomerata*.

UML Unified Modeling Language.

WFD Water Framework Directive.

Remerciements

Cette thèse est le résultat d'un travail personnel, bien sûr, mais il n'en aurait rien été sans l'entourage qui m'a fait confiance, poussé, questionné, intrigué.

Tout a commencé par une rencontre avec Alexis Tsoukiàs, devenu rapidement mon directeur de thèse en me poussant à mener ce projet. Tu as réussi à me surprendre à chaque rencontre par tes remarques à la fois profondes et décalées. Ma rencontre initiale avec toi, Olivier, m'a donné envie de te suivre, je te remercie de m'avoir suivi d'aussi près, de m'avoir donné tellement de suggestions et de directions (que je ne comprenais pas toujours), d'avoir été si disponible malgré ton emploi du temps plus que chargé et de ta constante attention aux détails et à la globalité. Gabriella, par tes encouragements, ton suivi amical et détendu, ton humour, ton ouverture, ta logique et ton efficacité, tu m'as permis de m'ouvrir à des champs inconnus, de mieux comprendre ce qu'on attendait de moi, d'aller découvrir le joyeux château de Dagshtul, entre autres. Pierre, tu m'as toujours donné des idées originales, des éclairages nouveaux, des pistes intéressantes et surtout prenant systématiquement en compte l'humain. Merci à tous les quatre d'avoir constitué une direction de thèse multicéphale, collaborative et si complémentaire.

Je me souviens de MISS ABMS qui m'a permis de découvrir (en plus du thème de la formation) l'équipe Green, notamment Christophe, Pierre, François ainsi que Hermine (comme on a ri) et Bruno. Un merci tout particulier à Bruno qui m'a écouté me plaindre, me réjouir ou douter pendant toute la durée de la thèse. Par les conversations multiples, tes conseils avisés ou aléatoires, tu as toujours su me rassurer et me faire repartir plein d'entrain et convaincu de l'intérêt des travaux que je menais. Je tiens à remercier tous les membres de mon comité de thèse (Pascale, Juliette et Christophe) pour la vision complémentaire que vous avez su m'apporter. C'est à ces comités que je dois l'orientation menaces de la thèse. Merci à Alexis Drogoul, Antony Jakeman, Olivier Tissot et Pascale Zaraté d'avoir accepté de faire partie de mon jury de soutenance.

Un immense merci à Katherine qui m'a accueilli et aiguillé en Australie en me faisant découvrir le terrain et rencontrer Ana. Ana, tu m'as ouvert les portes de l'ostréiculture du NSW grâce à ton réseau et ton enthousiasme. Il y a clairement eu un avant et un après. Ce travail y a énormément gagné.

Cette thèse n'aurait pas été la même sans l'enquête de terrain et les nom-

breux acteurs qui m'ont ouvert les portes et parlé, parfois longtemps, de leur profession, de leurs questionnements et leur vision de l'avenir. Merci à tous les ostréiculteurs et aux membres des pouvoirs publics tant Français qu'Australiens.

Je tiens à remercier en vrac l'ensemble des personnes qui ont compté pendant ma thèse, celles que j'ai découvertes et celles qui ont continué à être sur ma route ! N'oublions pas que nous sommes des animaux sociaux, et sans les autres, nous ne sommes pas grand chose. Une petite liste, clairement non exhaustive : les doctorants du LAMSADE et mes compagnons de G-EAU qui ont permis de nombreuses discussions à la cantine, Miguel avec qui j'ai perdu mes théories ; les chercheurs de G-EAU ; les apiculteurs de G-EAU ; les chercheurs et doctorants de GREEN ; Emeline et Ben, les awesome kids et ceux qui font rêver les dragons ; les amis de Montpellier ; la BAF ; les autres amis. Entre autres...

Je tiens aussi à remercier ceux sans qui tout cela n'aurait pas été possible, et ce depuis le début de ma vie, en m'encourageant, en me laissant libre de mes choix, en me facilitant la vie matérielle et en m'ayant donné la curiosité et le goût de la discussion, ma famille, tant mes parents que ma sœur Marie.

Résumé en Français

Ce chapitre est le résumé en Français de ma thèse. Il en donne les bases et avancées théoriques, la méthodologie suivie, une présentation des terrains de recherche ainsi que les résultats obtenus.

0.1 Introduction

La gestion de ressources naturelles est un enjeu planétaire et pressant dû notamment à la croissance de la population, à l'augmentation des besoins, ou à la pression urbaine (Steffen et al., 2015). La gestion de ressources naturelles ne se résume pas à un enjeu technique et à un savoir d'expert(s) mais relève plutôt de la science post-normale à cause des fortes incertitudes et de l'importance des enjeux (Funtowicz and Ravetz, 2003). Elle fait intervenir l'histoire, les règles et institutions existantes, les acteurs d'un territoire dépendant de ces ressources à des niveaux variés ainsi que les dynamiques environnementales. L'étude de ce domaine inscrit dans la complexité appelle donc fortement à l'interdisciplinarité (Bhaskar et al., 2010), une position que nous avons adoptée dans cette thèse où nous avons mis les disciplines au service de l'objet étudié. Nous avons aussi procédé avec prudence quant à la généralisation de résultats grâce à aller-retour constant entre cas particulier et cas général.

L'information et son partage sont postulés comme utiles à la réflexivité des acteurs sur leurs pratiques et leur territoire (Young et al., 2006). Sur un certain nombre de territoires, de tels outils ont été développés, de manière et avec des buts variés. Dans cette thèse, nous nous sommes demandés quelle pouvait être la conséquence de la mise en place de tels dispositifs, appelés artéfacts, tant au niveau de l'environnement qu'au niveau des acteurs et de leurs pratiques.

Pour étudier cette question, nous avons spécifiquement étudié des cas d'étude précis autour de l'ostréiculture. Nous avons sélectionné deux cas où des acteurs d'un territoire se mobilisent pour créer un artéfact. Nous nous sommes premièrement demandé pourquoi et comment les acteurs créent ces outils et qui sont ceux qui s'impliquent dans cette création. L'étude de ces cas, que nous présentons ci-dessous, nous a mené à comprendre que les acteurs se mobilisent en grande partie pour collectivement faire face à des "menaces". Cette découverte nous a amené à formuler et étudier la problématique suivante

:

Comment le partage de l'information entre des acteurs en interaction entre eux et avec une ou des ressources naturelles peut-il les aider à faire face à des menaces ?

0.2 Etat de l'art

Premièrement, nous décrivons la vision usuelle de la gestion collective de ressources naturelles telle qu'étudiée théoriquement et empiriquement dans la lignée de Ostrom. Nous proposons ensuite notre apport concernant la problématisation de la question de l'action collective pour la gestion de ressources naturelles autour de la notion de menaces. Finalement, nous mettons en lumière les enjeux de partage de l'information en regard des menaces.

0.2.1 Gestion de ressources naturelles et communs

Les travaux d'Elinor Ostrom et de nombreux autres chercheurs, focalisés sur l'étude des institutions mises en place par des acteurs utilisant et gérant une ressource dont ils ont besoin ont permis d'en terminer avec l'idée d'une nécessaire tragédie des communs. Selon cette fable, contée dans [Hardin \(1968\)](#), un commun laissé en autogestion est voué à disparaître car les acteurs les utilisant vont chercher égoïstement (rationnellement) à maximiser le bénéfice qu'ils peuvent tirer de la ressource, menant à son épuisement. Les solutions proposées sont une gestion publique ou une gestion privée.

Dans *Governing the commons*, [Ostrom \(1990\)](#) démontre empiriquement que dans certaines conditions, des acteurs ont réussi à créer, maintenir et faire évoluer des institutions qu'ils considèrent légitimes pour gérer de façon durable et équitable des ressources qui doivent être partagées. Les biens sont classés selon deux dimensions, l'exclusivité (peut-on empêcher quelqu'un de profiter de la ressource ?) et la substractabilité (l'utilisation du bien par un acteur, par prélèvement par exemple, limite-t-elle son utilisation par d'autres acteurs ou a-t-elle un impact sur le bien ?). La réponse à ces questions permet de distinguer quatre principaux types de bien : public, club, privé et commun. Le commun est dans cette classification une ressource non exclusive et substractable. L'accès, l'usage et la gestion de ces biens et ressources sont classés sous un angle de faisceaux de droits qui se superposent, donnant des droits variés à différents acteurs et à différents moments ([Schlager and Ostrom, 1992](#)).

Une question fondamentale présente dans la thèse de Hardin et vérifiée empiriquement dans de nombreux domaines est la problématique du dilemme social, situation dans laquelle un individu a intérêt à suivre son intérêt personnel plutôt que de collaborer avec l'autre ou les autres. Une telle personne est alors appelée un passager clandestin. Dans un travail collectif, il peut être

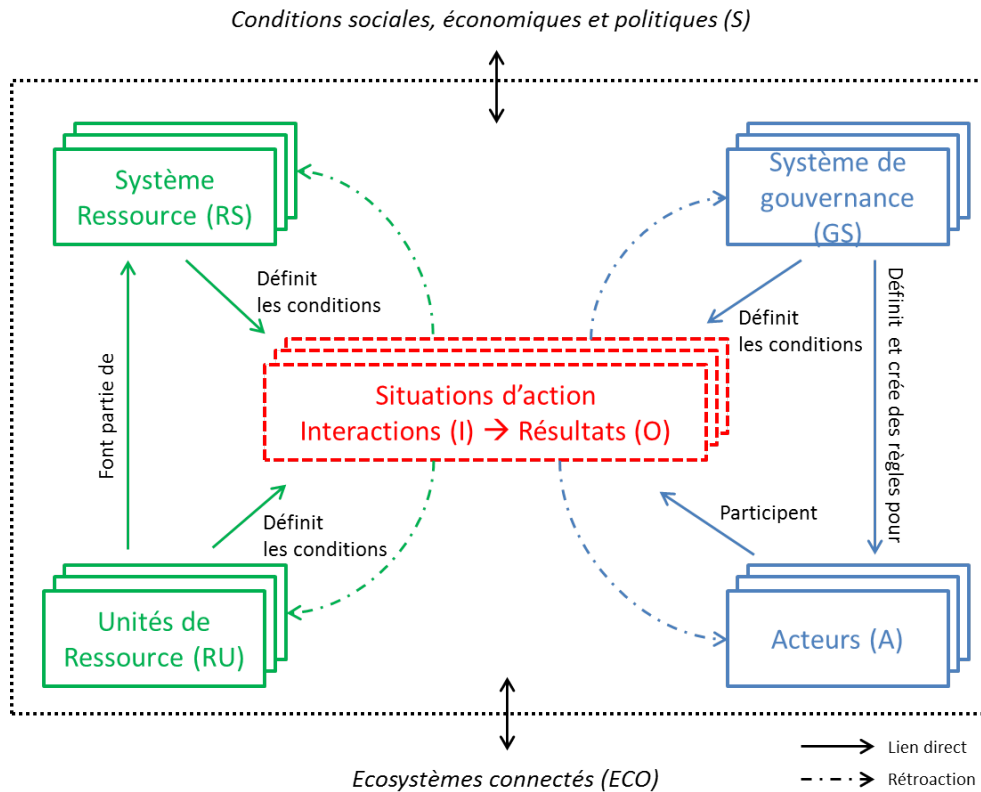


Figure 1: Cadre des Systèmes Socio-Ecologiques (McGinnis and Ostrom, 2014)

tendant de laisser les autres faire (investir du temps ou de l'argent) pour profiter du résultat. Or si chacun suit son intérêt personnel, le résultat global ne pourra être atteint. Les communs peuvent se trouver dans cette situation. Pour s'en sortir, plusieurs stratégies sont envisageables, comme la communication, l'établissement de contrats ou une vision de son intérêt à long terme (qui se confond alors avec l'intérêt collectif).

L'étude des communs a permis l'établissement d'un cadre appelé le cadre des *systèmes socio-écologiques* qui nous a guidé pour l'exploration des cas d'étude de la thèse (Folke et al., 2005; McGinnis and Ostrom, 2014) (Figure 1). Ce cadre met en lien un système de ressources (par exemple une forêt) que des acteurs (des forestiers, des chasseurs) utilisent pour extraire des unités de ressources (des arbres, des animaux) en fonction d'un système de gouvernance (collectivités, parcs naturels, associations ...). Ces éléments forment des situations d'action favorisant certains types d'interactions menant à des résultats, tant pour les acteurs que pour le système de ressources. Ce système socio-écologique est vu comme un système complexe où les rétroactions ont un rôle important : ces situations d'interaction rétroagissent sur les autres éléments.

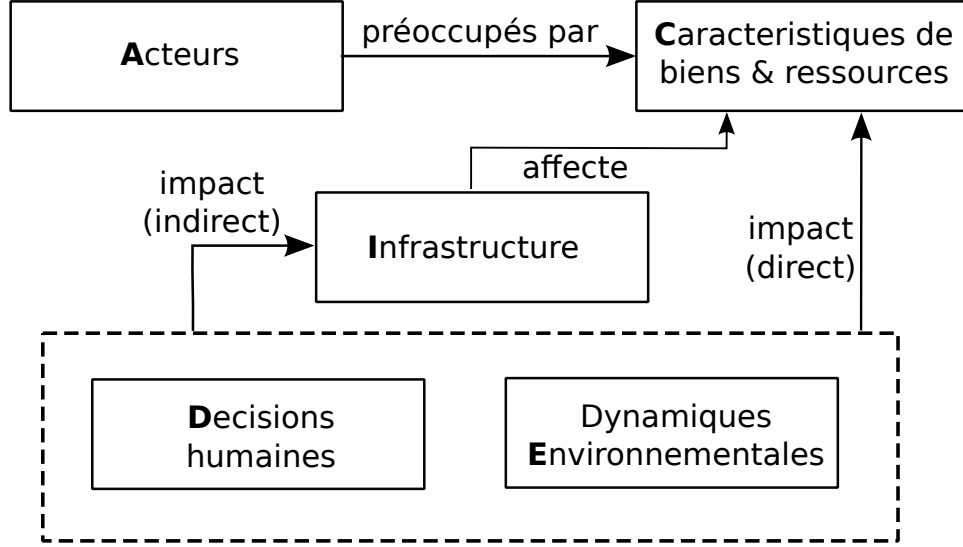


Figure 2: Relations entre les éléments constitutifs d’une menace $\langle \mathcal{A}, \mathcal{C}, I, D, E \rangle$.

0.2.2 Menaces

L’approche développée concernant la gestion de ressources collectives met l’accent sur la ressource et les règles que les acteurs ont mis en place. Or, l’étude des cas montre qu’une partie de l’action collective est déclenchée par une perception commune de menaces qui pèsent sur certaines caractéristiques importantes des ressources et bien utilisés. Cette action collective peut se traduire par la mise en place de règles, de mesures ou d’artéfacts de partage de l’information.

Une menace, par exemple la possibilité de pertes de récoltes à cause d’un ravageur, est indépendante du régime de propriété du bien sous-jacent. Ces menaces peuvent agir sur un ensemble de champs de même type ou sur des ressources halieutiques partagées.

Nous avons défini les menaces dans le cadre de la gestion de ressources naturelles à l’aide du 5-uple $\langle \mathcal{A}, \mathcal{C}, I, D, E \rangle$ (Figure 2). \mathcal{A} est un groupe d’acteurs qui s’inquiètent pour certaines caractéristiques \mathcal{C} de biens ou de ressources (appelés actifs) qu’ils possèdent ou utilisent. I contient les infrastructures au sens de [Anderies and Janssen \(2013\)](#), *i.e.*, humaines (du canal aux règles) ou naturelles. L’infrastructure est ici considérée dans un sens large comme un ensemble de contraintes ou d’éléments qui pourraient avoir une influence sur certaines caractéristiques des actifs \mathcal{C} . Finalement, D et E sont les événements comme les décisions humaines (D) et les dynamiques environnementales (E) qui peuvent affecter, directement ou indirectement à travers I , les actifs.

Cette définition permet de capturer les caractéristiques essentielles à la description d’une menace. Elle est volontairement subjective et relative à un

Table 1: Une typologie des menaces

		<i>Internalité</i>	
		<i>Faible</i>	<i>Forte</i>
<i>Exclusion</i>	<i>Difficile</i>	Publique	Commune
	<i>Aisée</i>	X	Privée

ensemble d'acteurs, ce qui la distingue de la vision habituelle d'un risque qui se veut une probabilité objective.

A ce stade, il manque un moyen pour les acteurs d'envisager des actions pour lutter contre les menaces. Nous avons identifié deux axes menant à une typologie permettant de repérer des stratégies d'actions pour les acteurs une fois d'accord sur ses caractéristiques principales. Les deux axes que nous avons retenus sont : l'*internalité* et l'*exclusion*. Une menace est interne si la menace émane des acteurs de \mathcal{A} eux-mêmes ou si elle ne concerne qu'eux. Une menace est exclusive s'il est possible pour un acteur de s'extraire seul de la menace. Cette classification nous a mené à définir trois types principaux de menaces découverts grâce aux cas d'étude (Tableau 1). Premièrement, les menaces *communes* (forte internalité et exclusion difficile), les plus classiques, qui concernent la présence de passagers clandestins entre autres. Ce sont celles qui sont la focale de la littérature sur la gestion collective de ressources naturelles. Deuxièmement, les menaces *privées* (forte internalité et exclusion aisée) pour lesquelles la lutte peut nécessiter un partage d'information en plus d'un apprentissage des acteurs. Troisièmement, les menaces *publiques* (faible internalité et exclusion difficile) sont des menaces qui ne peuvent être réglées de l'intérieur par les seuls acteurs touchés, elles sont particulièrement importantes dans des systèmes ouverts aux influences extérieures. Les cas d'étude que nous avons menés ne nous ont pas permis d'identifier des menaces de faible internalité et d'exclusion aisée. Cela n'empêche pas leur possible existence dans d'autres situations.

0.2.3 Information et partage de l'information

C'est grâce à la perspective des menaces que nous avons étudié l'information dans le cadre de gestion de ressources naturelles renouvelables. Cette notion est difficile à cerner car l'information peut facilement être vue partout, au travers d'éléments repérés dans l'environnement, d'apprentissages personnels, d'échanges avec d'autres acteurs ou de connaissances accessibles via des artéfacts. La définition de l'information diffère grandement en fonction de la focale envisagée, de la discipline, de l'objectif.

Afin de pouvoir distinguer l'information de la non information, nous avons retenu la définition suivante due à Bateson (1972): "l'information est une dif-

férence qui fait la différence”. Cette définition permet une vision subjective de l’information adaptée à la subjectivité de la notion de menace : ce qui fait information pour un acteur ne fait pas forcément information pour un autre.

Nous pouvons observer plusieurs problématiques spécifiques à la gestion de ressources naturelles concernant le partage de l’information via des artefacts. Premièrement, contrairement aux grands réseaux de partage d’information comme Wikipedia, l’anonymat est limité et peut amener certains à se retenir de partager leurs expériences. Deuxièmement, un comportement stratégique de la part des acteurs peut se manifester. Ainsi si certains résultats sont attendus, les observations inscrites peuvent être biaisées. Troisièmement, la question du passager clandestin subsiste puisque certains acteurs peuvent se reposer sur le travail de partage d’information d’autres acteurs sans participer à l’effort collectif. Il s’agit là d’un dilemme du second-ordre dans les cas où l’artéfact est destiné à lutter contre des dilemmes sociaux observés. Un dernier problème résulte de l’auto-réalisation, telle une prophétie, liée au partage de certaines informations : la nouvelle d’un possible épuisement d’une ressource peut accélérer son épuisement en faisant évoluer les schémas mentaux d’une gestion d’une ressource renouvelable vers celui d’une ressource minière où le premier arrivé est le premier servi, comme le montre l’exemple étudié par [Villena and Zecchetto \(2010\)](#).

En plus des problèmes évoqués, il est nécessaire de garder en tête que le partage de l’information peut se faire de multiples façons qui dépassent le cadre des artefacts qui sont le centre d’attention de notre travail. Ainsi les acteurs partagent-ils l’information via leurs réseaux ou lors de rencontres en direct entre autres. Ces réseaux sont d’une importance fondamentale et sont l’objet de nombreuses études ([Bodin and Prell, 2011](#)).

La complexité de la définition et l’ubiquité de l’usage de l’information nous a amené à défricher la question de l’information et de son partage pour faire face à des menaces en suivant trois axes principaux : pourquoi partager l’information ? quelle information partager ? comment la partager ?

Si la menace est publique, l’information permet de légitimer l’action de certains acteurs ou de faire du lobbying. Dans le cas d’une menace commune, elle peut permettre de gérer les conflits ou de limiter les passagers clandestins. Si la menace est privée, l’information peut servir à comprendre les dynamiques environnementales, ou à augmenter les connaissances. Les types d’information à partager sont extrêmement variés, allant de mesures quantitatives environnementales à des règles à porter à la connaissance de tous, en passant par les décisions prises par les acteurs. Les moyens de partage de l’information sont aussi multiples allant du simple échange interpersonnel, aux réunions de groupe ou au partage institutionnel. La description d’un artéfact de partage de l’information peut se faire en décrivant les éléments suivants : but, type, lecture, écriture, granularité et caractère dynamique.

0.3 Methodologie

Lors de la thèse, nous avons suivi deux directions majeures pour étudier la question du partage de l'information. La première a consisté à explorer des cas d'étude réels, la seconde à développer un modèle multi-agents.

L'étude de deux cas réels centrés sur l'ostréiculture, en France et en Australie, nous a permis de nous imprégner de situations existantes tout en réduisant les fortes limites liées à la focalisation sur un cas unique, comme monter trop hâtivement en généralité, et la dispersion liée à l'étude de cas trop nombreux pour la durée d'une thèse. Pour le cas français, nous avons interviewé 17 ostréiculteurs (sur les 500 de la lagune), 1 membre de syndicat mixte et participé à 1 conférence et 5 réunions avec des acteurs. Pour le cas australien, nous avons interviewé 13 ostréiculteurs situés dans 9 estuaires différents (sur 320), 3 membres des pouvoirs publics et participé à une rencontre entre acteurs. Nous avons initialement choisi de nous concentrer sur un unique estuaire en Australie, mais la plupart des ostréiculteurs de cet estuaire autrefois important ont fait faillite à cause d'un virus particulièrement virulent dont nous parlerons plus tard. Nous avons donc opté pour une étude de plusieurs estuaires aux problématiques similaires.

Les entretiens réalisés, 34 au total, étaient semi-ouverts et guidés par les éléments majeurs suivants : quelles sont les conditions locales et quelles sont vos pratiques ; quelle est votre vision du rôle des ostréiculteurs dans la gestion de l'environnement (au sens large) et quelle est votre implication ; quelle est votre relation avec les autres ostréiculteurs et les artefacts étudiés.

L'influence des artefacts de partage de l'information a été mesurée selon deux méthodes, une qualitative et une quantitative. Nous avons utilisé le cadre ENCORE (externe, normatif, cognitif, opérationnel, relationnel et équité) (Ferrand, 2004) qui permet une description d'aspects qualitatifs sur 6 dimensions pour différents acteurs ou groupes d'acteurs, dans notre cas, en comparant les situations avec et sans la présence d'artefacts.

En complément de ces études de cas réels, nous avons développé un modèle multi-agents. Un modèle multi-agent est un laboratoire expérimental *in silico* permettant de construire et tester précisément différents scénarios (notamment de partage d'information) afin de comparer leurs conséquences. Cet outil est particulièrement utile pour étudier des systèmes complexes et les relations entre niveaux micro (au niveau des agents) et macro (au niveau global) (Edmonds and Meyer, 2013a). Il est souple dans la définition du fonctionnement interne des entités ainsi que de leurs interactions et ne demande pas de résolution mathématique. Plus précisément, nous avons développé un modèle en utilisant le logiciel Cormas (Bousquet et al., 1998; Le Page et al., 2012) que nous avons couplé au logiciel de statistiques R (R Core Team, 2015). Nous nous sommes fortement appuyé sur les techniques classiques de conception informatique orientée-objet (comme UML) et utilisé un protocole dédié aux modèles multi-agents dans le cadre de la gestion de ressources naturelles, le protocole

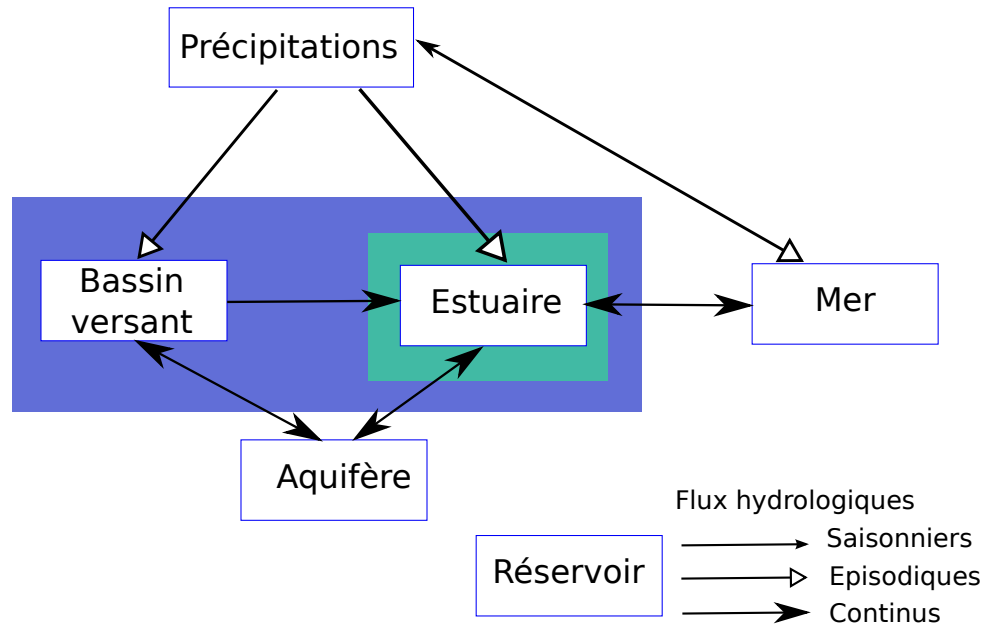


Figure 3: Flux hydrologiques majeurs d'un bassin versant côtier.

ODD+D (Overview, Design concepts and Details + Decisions) ([Grimm et al., 2006](#); [Müller et al., 2013](#)).

0.4 Etude de cas

Les cas d'étude sont centrés sur l'ostréiculture, une profession qui a été, à notre connaissance, peu étudiée par la communauté des chercheurs sur la gestion collective de ressources naturelles. Au commencement de l'enquête, nous nous étions assuré que les cas d'étude choisis permettraient d'investiguer le partage de l'information car les acteurs avaient développé ou étaient en train de mettre en place des artefacts.

0.4.1 Généralités et intérêt du cas de l'ostréiculture

La culture d'huîtres se fait au niveau d'estuaires, espaces ouverts et points de sortie de bassins versants côtiers (Figure 3). Les tables sur lesquelles sont cultivées les huîtres sont donc situées à l'aval de ces bassins. La qualité de l'eau est fortement influencée par les activités dans l'estuaire et dans le reste du bassin versant. Des pics de pollution microbiologique ont régulièrement lieu, à la suite de fortes pluies ou de défaillances de stations d'épuration. Ces pics obligent les autorités sanitaires à interdire temporairement la vente d'huîtres, ce qui a un impact économique pour les ostréiculteurs et pour la région en

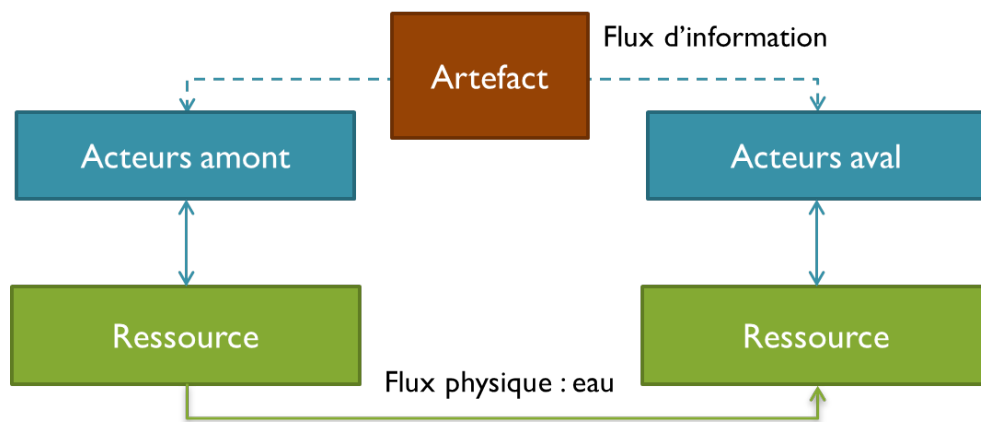


Figure 4: L'information permet-elle de boucler la boucle ?

général. La qualité de l'eau est dans le cas présent assimilée à la quantité d'*E. coli* dans l'eau, l'indicateur habituellement utilisé. Les estuaires sont des lieux aux usages multiples avec des utilisateurs exerçant divers droits d'usage (accès, extraction) et ayant des besoins différents pour la qualité de l'eau. Les ostréiculteurs sont les acteurs requérant les conditions de qualité les plus exigeantes. Une eau de qualité assez bonne pour garantir la production d'huître consommables vivantes est assez bonne pour tous les autres usages. Les ostréiculteurs ont donc un fort intérêt à travailler dans un environnement le plus préservé possible. Remarquons qu'une eau riche en microbiologie est une eau favorable au développement des huîtres, organismes filtrants, bien qu'elle ne soient pas consommables à ces moments précis.

La difficulté que les ostréiculteurs rencontrent est due au fait que la qualité de l'eau est surtout liée aux comportements d'acteurs situés à l'amont du bassin versant. Le flux physique d'eau arrivant dans l'estuaire (en négligeant les échanges avec la mer) est donc situé en dehors de la zone d'action des ostréiculteurs, ou tout du moins, n'est pas directement lié à leurs pratiques : bien que similaire à l'agriculture par la fixité des installations, il n'est pas possible à un ostréiculteur, ni même à un groupe d'ostréiculteurs, de changer la qualité de l'eau devant sa ferme par des actions personnelles directes sur la ressource alors qu'un agriculteur peut tenter d'utiliser des pesticides pour se prémunir contre une attaque d'insectes.

Comment les ostréiculteurs pourraient-ils trouver le moyen d'exercer une influence sur la qualité de cette eau située au centre de leur activité ? Y a-t-il une possibilité pour eux de remonter ce flux physique d'eau et ainsi de fermer la boucle du système dans lequel ils s'inscrivent ? Le partage de l'information via des artefacts est-il une solution possible et utile ? (Figure 4)

0.4.2 Cas spécifiques et artéfacts focaux

Avant de répondre à ces questions, nous allons entrer dans le détail des cas d'étude évoqués dans la section Méthodologie.

0.4.2.1 Etang de Thau, France - OmegaThau

L'étang (ou lagune) de Thau est situé dans le sud de la France, près de la ville de Sète. La culture d'huîtres y est développée depuis plus de 100 ans et a pris son essor après 1945 ([Giovannoni, 1995](#)). La lagune est lieu d'usages multiples (pêcheurs, ostréiculteurs, plaisanciers, bateaux de commerce), parfois conflictuels. Plus de 500 entreprises ostréicoles, pour 2000 emplois permanents, sont présentes sur la lagune. Le Syndicat Mixte du Bassin de Thau a déclaré comme prioritaire la préservation des petits métiers (nom utilisé pour désigner pêcheurs et ostréiculteurs) dans le [Schéma d'Aménagement et de Gestion des Eaux \(SAGE\)](#) dont le Syndicat a coordonné la rédaction.

Dans le cadre de la mission du Syndicat Mixte, un outil de connaissances, de suivi et de prédiction des flux microbiologiques a été développé : OmegaThau (Figure 5, à gauche). Cet outil utilise un modèle basé sur des modèles hydrologiques, un réseau de capteurs et les prévisions météo pour réaliser ces prévisions de flux. Les ostréiculteurs peuvent alors être prévenus au plus tôt d'une possible interdiction de vente imminente afin qu'ils s'y préparent.

Les huîtres cultivées sur l'étang de Thau, la [Pacific Oyster *Crassostrea Gigas* \(PO\)](#), proviennent principalement d'écloseries industrielles produisant du naissain ainsi que de captages naturels directement réalisés dans l'étang. Les écloseries produisent deux types d'huîtres : des diploïdes et des triploïdes, huîtres provenant d'un croisement entre une huître quadriploïde et une diploïde. Les huîtres triploïdes sont stériles et ne produisent pas de laitance. Elles arrivent à maturité en 2 ans (au lieu de 3 pour les diploïdes) ce qui leur confère un fort avantage économique. Depuis 2008, les huîtres du bassin sont touchées par un herpès virus OsHV-1 qui élimine jusqu'à 90 % de la population en quelques jours, au printemps, quand les eaux se réchauffent. Les entretiens avec les ostréiculteurs ont montré que là résidait leur préoccupation principale et non sur la question microbiologique, contrairement à ce que nous postulions au départ.

0.4.2.2 New South Wales, Australie - Environmental management systems

La culture des huîtres dans le [New South Wales \(NSW\)](#) emploie 1600 personnes réparties dans 320 entreprises et 32 estuaires le long des 1300 km de côte. Un estuaire peut compter entre 3 et 30 entreprises. Ces estuaires ont des conditions locales différentes, notamment à cause de la présence ou non d'un fleuve ou de grandes villes. Les exigences de qualité de l'eau sont similaires aux Françaises.

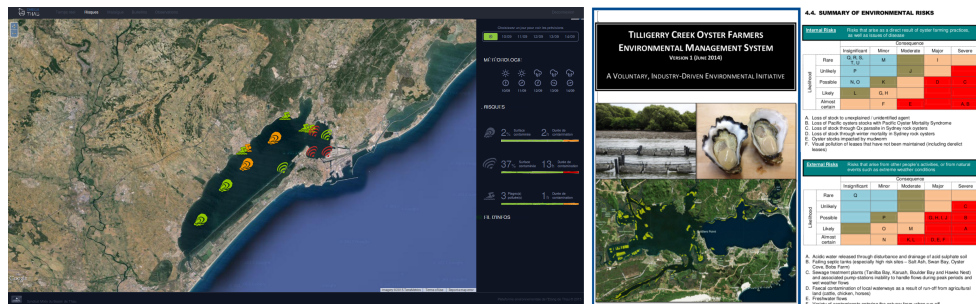


Figure 5: Les principaux artefacts étudiés. A gauche, le système d'observation OmegaThau (France) ; à droite, un système de management environnemental (Australie).

L'huître cultivée en majorité est une huître locale, la *Sydney Rock Oyster* *Saccostrea Glomerata* (SRO), à laquelle s'ajoute la culture de PO triploïdes stériles (cette huître en diploïde est considérée comme invasive) dans certains estuaires. La production globale a décliné, passant de 9400 tonnes en 1976 à 3500 en 2012 à cause de diverses épizooties. Le même virus que celui qui sévit en France, l'herpès virus OshV-1, a fait son apparition dans le NSW en 2012, réduisant à néant les efforts de nombreux ostréiculteurs.

Depuis 2010, grâce à quelques ostréiculteurs proactifs et à l'intervention d'une association mi-publique mi-privée, Ocean Watch, l'industrie ostréicole se dote petit à petit d'outils de partage d'information appelés *Environmental Management System* (EMS) (Figure 5, à droite). Ces artefacts sont des livrets d'information disponibles sur internet et localement, écrits au niveau des estuaires (en 2016, 50 % des estuaires étaient équipés). Ils contiennent des informations sur le bassin versant et l'estuaire dans lequel les ostréiculteurs agissent, une description des pratiques de ces acteurs ainsi que l'ensemble des risques perçus par les ostréiculteurs, qu'ils soient internes (directement liés à l'activité ostréicole) ou externes (ayant un impact sur cette même activité). Les ostréiculteurs interviewés se sont montrés fiers de l'existence de cet outil qui a mené à l'émergence d'organisations plus structurées qu'auparavant pour cette industrie, comme Australia's Oyster Coast ou Sapphire Coast Wilderness Oysters.

0.4.2.3 Discussion sur les cas étudiés

Les deux cas d'étude concernent l'industrie ostréicole et sont comparables au niveau des modes de production, d'autant que les niveaux de développement des pays sont similaires. Il est donc raisonnable de comparer ces cas. Malgré de nombreuses similarités, il existe deux différences importantes qu'il nous faut noter et que nous avons pu identifier grâce à l'application systématique du cadre des systèmes socio-écologiques aux cas.

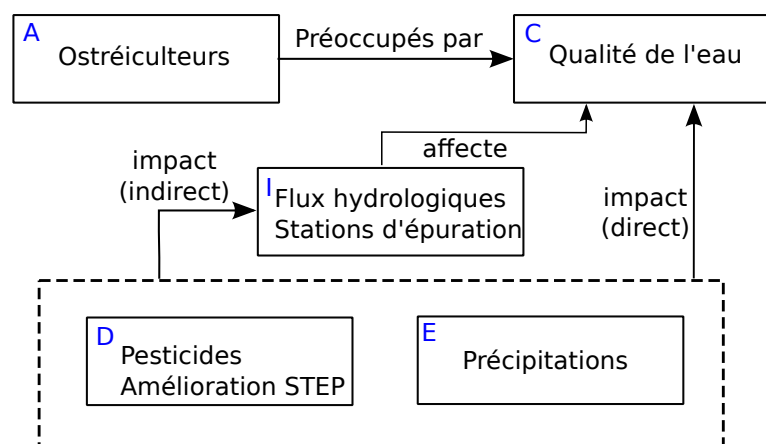


Figure 6: La menace microbiologique sur la qualité de l'eau.

La première est une question de taille : plus de 500 fermes cultivent des huîtres sur le bassin de Thau alors que les estuaires australiens ne comptent pas plus de 30 fermes chacun. Cela a des conséquences sur la capacité collective d'organisation et de la participation à la création d'artéfacts de partage d'information. Ce n'est pas la même chose de réunir 30 ou 500 personnes pour un projet commun.

La seconde est liée à la notion de communauté ("community"). Ce concept anglo-saxon est fortement présent dans les entretiens réalisés auprès des ostréiculteurs australiens qui se sentent redevables envers leur communauté alors qu'il ne semble pas spécialement pris en considération par les ostréiculteurs français.

0.5 Résultats

L'étude de terrain nous a permis d'identifier les deux menaces principales auxquelles les ostréiculteurs sont soumis dans les deux cas étudiés : la question microbiologique et celle de l'herpès virus. Ces deux menaces sont de natures fondamentalement différentes et justifient des stratégies d'approches, ici étudiées via le partage de l'information, radicalement distinctes.

0.5.1 Une menace publique : la microbiologie

0.5.1.1 Formalisation de la menace

Comme évoqué plus haut, la menace microbiologique que l'on peut voir comme une détérioration de la qualité de l'eau, est une menace économique pour les ostréiculteurs ainsi qu'une menace d'image globale pour la région : des ferme-

tures régulières donnent une mauvaise image de l'eau dans la région résultant en d'importantes pertes au niveau du tourisme.

Cette menace est un exemple de menace publique pour les ostréiculteurs puisqu'elle est de faible internalité (ce ne sont pas les ostréiculteurs qui sont à l'origine des variations de la qualité de l'eau) et d'exclusion difficile (un ostréiculteur ne peut pas changer la qualité de l'eau sur sa ferme).

Nous pouvons utiliser le cadre que nous avons présenté en Figure 2 pour l'appliquer à la question de la qualité de l'eau et cerner les enjeux liés à cette menace (Figure 6).

0.5.1.2 Stratégies de partage de l'information

Les stratégies utilisées pour agir contre cette menace par certains acteurs des terrains étudiés sont différentes, tant sur le plan technologique que sur les informations partagées et la manière de les partager. En Australie, l'artéfact est un document (Environmental Management System, EMS), rédigé par des ostréiculteurs, soutenus par les collectivités locales et l'Etat ; en France, l'artéfact est un système d'information (OmegaThau), développé principalement par les collectivités locales.

L'utilisation du cadre ENCORE nous a permis de déterminer l'évolution de la situation des systèmes socio-écologiques concernés suite à la mise en place de ces artéfacts, au niveau de l'état de la ressource, de la relation que les acteurs entretiennent avec la ressource et des relations des acteurs entre eux, qu'ils appartiennent à la même catégorie ou non.

Dans le cas australien, les conséquences sur la ressource pourraient être mesurables à long terme, mais, d'après les entretiens, les acteurs eux-mêmes conviennent qu'il est difficile de mesurer un véritable impact direct de l'artéfact sur l'état de la ressource. En effet, les éléments soulevés et les informations recueillies ne peuvent mener qu'à des actions aux conséquences à long terme et visent à une adéquation plus grande des pratiques de chacun vis-à-vis de la ressource, sans effet immédiat. La première conséquence de la rédaction des EMS réside dans l'évolution de la relation que les acteurs entretiennent entre eux. Durant la rédaction elle-même, les ostréiculteurs ont d'abord globalement renforcé la cohésion des acteurs au sein de l'industrie, même s'il existe un contre-exemple. Ils ont par ailleurs créé une relation directe avec les collectivités locales qui ont vu leur vision de l'ostréiculture évoluer de celle d'une tolérance d'utilisateurs d'une ressource publique (l'estuaire) vers celle de soutien d'un ensemble de sentinelles de l'environnement qui ont tous en tête l'importance de la préservation et de la surveillance de la ressource eau des estuaires, voire des bassins versants. De plus, l'existence de ce document contraint publiquement les ostréiculteurs à des actions concrètes et mesurables garantissant des pratiques durables au sein de l'ostréiculture. S'engager ainsi sur la place publique légitime le rôle des ostréiculteurs en tant que déclencheurs de pratiques au sein d'une communauté d'acteurs vaste (Paget et al., 2016).

Dans le cas français, l'artéfact a officiellement pour but de mieux comprendre et prévoir l'évolution de la ressource. Il a demandé 7 ans de développement et un investissement public conséquent en temps et en argent. L'artéfact final atteint son but annoncé : les connaissances sur les flux hydrologiques et les prévisions sont améliorées. La ressource est donc mieux comprise par les collectivités locales et les informations sont partagées avec les membres du syndicat conchylicole. En revanche, son existence n'est que peu connue par les ostréiculteurs que nous avons interviewé et son efficacité souvent remise en question ("ça ne m'apporte rien de plus que la météo.") et encore moins par d'autres acteurs du territoire. Les relations entre acteurs ou la cohésion entre ostréiculteurs ne semble pas avoir évolué sur les dimensions du cadre EN-CORE. Il faut néanmoins rappeler que le Syndicat Mixte du Bassin de Thau a une forte tradition de concertation et de consultation des acteurs et populations locaux et a mis au centre de sa politique de développement territorial les "petits métiers", *i.e.* ostréiculteurs et pêcheurs ([SAGE-Thau, 2015](#)).

Rappelons que la définition que nous avons choisie pour l'information est "une différence qui crée une différence". Cela nous amène à nous demander pour qui cette différence existe et en quoi elle consiste. L'analyse de ces deux cas d'étude montre que la différence que peut créer un artéfact peut être limitée aux conséquences prévues, voire ne pas créer de différence, comme dans le cas français où les acteurs n'obtiennent pas plus d'information qu'avec la météo, ou aller plus loin et atteindre un ensemble d'acteurs dépassant les créateurs de l'information.

0.5.2 Une menace privée : l'herpès virus OsHV-1

0.5.2.1 Formalisation de la menace

Cette menace est spécifique à l'activité ostréicole puisque le virus agit exclusivement sur les huîtres. Il s'agit donc d'une menace fortement interne. Certains ostréiculteurs semblent échapper au virus par leurs pratiques. Le virus est donc une menace dont il est possible de s'exclure. Il peut donc être considéré comme une menace privée. Cette conclusion est forte et sera utile pour la modélisation que nous développeront plus bas.

De même que pour le virus, nous pouvons formaliser la menace en utilisant le cadre $\langle \mathcal{A}, \mathcal{C}, I, D, E \rangle$ que nous avons développé (Figure 7).

0.5.2.2 Stratégies de partage de l'information

Cette menace est encore mal comprise par les acteurs et par les scientifiques qui l'étudient ([Pernet et al., 2014](#)). De plus, le virus n'agit qu'une seule fois par an. Pourtant, ce sujet est le premier sujet d'inquiétude évoqué par les acteurs lors des entretiens menés. Par ailleurs, notre point de focale se situe au niveau de la conséquence de la mise en place d'artéfacts de partage d'information. Comment étudier ces conséquences, tout en maîtrisant les modalités de partage

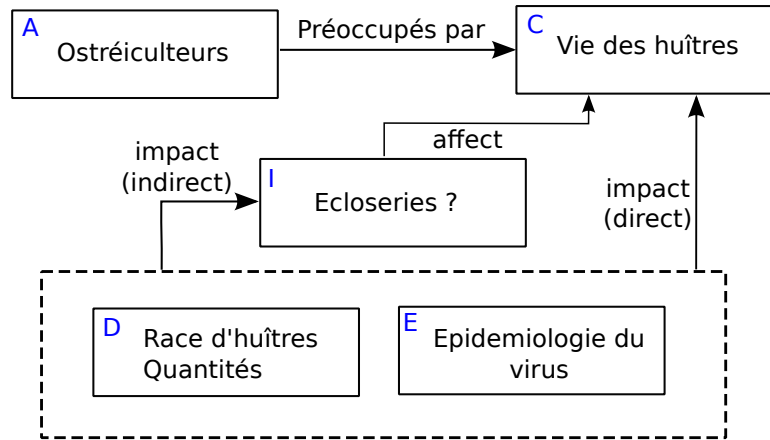


Figure 7: La menace virale sur la vie des huîtres.

d'information sur un sujet et une temporalité qui dépassent largement celui d'une thèse ? Pour les raisons exposées à la section méthodologie, nous avons fait le choix de créer un modèle puis une simulation multi-agents qui répond aux exigences de la question que nous nous posons tout en permettant une maîtrise et un suivi des différents paramètres.

La présentation du modèle suit le protocole ODD+D. La figure 8 montre le fonctionnement simplifié du modèle multi-agent. Nous nous sommes demandé quels pouvaient être les effets du partage d'information pour l'adaptation à une menace privée (ici le virus). Des ostréiculteurs cultivent des huîtres qui se font attaquer par un virus au fonctionnement inconnu, mais fixe dans le modèle, que les acteurs cherchent à déterminer. Cette mortalité est fonction de la race d'huître et de la quantité d'huître par table. Pour cela, ils observent la mortalité sur leur ferme et partagent leurs résultats selon plusieurs scénarios : pas de partage, partage via un réseau social et/ou un système centralisé de partage de l'information. Les agents ostréiculteurs, conçus en s'inspirant de l'architecture de type BDI (belief, desire, intention), sont de plusieurs types, *i.e.* suivent plusieurs systèmes de décision, ce qui mène à une hétérogénéité des agents, une des forces de la modélisation multi-agents. Les différents agents sont de type "économique" s'ils cherchent à maximiser leur profit (en fonction de leurs croyances), "conservative" s'ils changent de stratégie seulement lorsqu'ils sont mécontents ou "conscient" s'ils choisissent de ne cultiver que des huîtres diploïdes naturelles. Une fois l'information partagée, les agents la recueillent et élaborent une stratégie qui sera appliquée l'année suivante.

Pour comparer les 1296 différents scénarios (en fonction des types et quantités d'agents, des modalités de prise de décision, de l'épidémiologie du virus et du partage d'information), nous avons défini des indicateurs. Nous avons mesuré l'écart des croyances des agents sur le mode opératoire du virus tant entre agents qu'avec sa vraie dynamique. Le modèle montre que la disper-

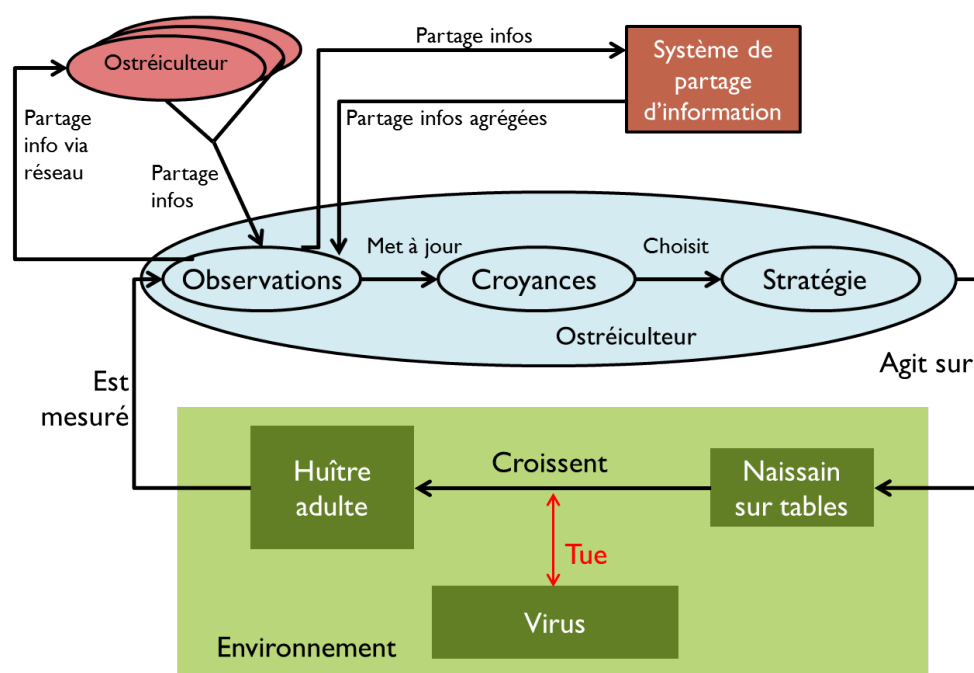


Figure 8: La boucle principale du modèle.

sion des croyances des agents était systématiquement plus faible lorsqu'un système centralisé de partage d'information était présent mais que celles-ci ne convergeaient pas forcément vers la réalité de l'épidémiologie du virus. Nous avons aussi mesuré les conséquences sur les pratiques des acteurs grâce à un indicateur mesurant pour chaque scénario l'étape à partir de laquelle les agents cessent de modifier leurs stratégie. Le modèle amène à conclure que la présence d'un système de partage d'information, ainsi que d'un réseau social, mène à un choix final de stratégie précoce. En revanche, les conséquences de ces scénarios sur la production globale au cours de la période testée (20 ans) sont limitées. Nous observons en fait que la production augmente avec l'hétérogénéité des acteurs. Une population d'acteurs uniquement "economicus" produit sensiblement moins d'huîtres que lorsqu'elle est mélangée à des agents "conservative" et "conscious" car le domaine d'exploration des pratiques possible s'élargit avec la diversité d'acteurs. Ainsi, les "economicus" laissent de côté les huîtres naturelles initialement vues comme moins intéressantes économiquement alors qu'elles se révèlent plus résistantes face au virus.

0.6 Discussion

Dans cette thèse, nous explorons les possibles impacts de la mise en place de systèmes de partage de l'information pour la gestion de ressources naturelles.

Cette question et l'étude de cas réels nous a amené à développer le concept de menaces, menaces autour desquelles les acteurs effectuent des actions collectives, notamment le développement de systèmes de partage d'information.

0.6.1 Sur l'approche méthodologique

0.6.1.1 Etudes de terrain

Lorsque nous parlons de gestion de ressources naturelles, il est fondamental de confronter les idées théoriques et la réalité. Dans cette thèse, nous avons suivi ce principe qui a été à la base des recherches d'Elinor Ostrom et de la philosophie générale de recherche que nous avons suivie ([Janssen and Ostrom, 2006](#)). L'étude de terrain, guidée par le cadre SES, nous a permis d'identifier des éléments qui n'auraient pas pu être identifiés si nous étions restés dans le laboratoire. En revanche, il faut se garder de généraliser hâtivement tous les éléments que nous pouvons rencontrer sur le terrain, car certains peuvent se révéler contextuels et d'importance mineure. Pour contrer cet effet négatif, nous avons choisi d'étudier deux cas comparables mais suffisamment distincts pour limiter ces risques. Après avoir passé du temps à étudier le premier cas d'étude (l'étang de Thau), nous avons formulé des hypothèses dont certaines ont pu être rejetées lors de l'étude du second cas qui nous a conforté dans certaines directions et ouvert d'autres voies. L'étude de deux cas permet d'éviter les écueils principaux, mais le temps à consacrer à chaque cas force à se restreindre à un nombre de cas limités. Nous devons alors choisir un nombre de cas adapté au temps disponible, surtout sur le temps d'une thèse qui n'est pas principalement consacrée aux cas en eux-mêmes.

0.6.1.2 Le cadre des systèmes socio-écologiques (SES)

Ce cadre nous a guidé lors de l'exploration de ces systèmes complexes, permettant de ne pas oublier d'élément fondamental. Nous l'avons utilisé pour comparer les deux cas d'étude et identifier certaines variables qui pouvaient expliquer des différences. Les systèmes socio-écologiques sont des systèmes complexes où interagissent de nombreuses entités humaines ou non et aux rétroactions multiples. Il est aisé de s'y perdre et nous recommandons de suivre ce cadre pour l'enquête de terrain qui peut être longue et laborieuse.

Cependant, lorsque nous avons étudié le terrain, nous avons découvert que nous ne pouvions y inscrire les éléments qui concernaient les menaces et qui sont au cœur de l'action collective, en tout cas dans les cas d'étude sur l'ostréiculture. Nous avons donc proposé un certain nombre de variables pour compléter le cadre SES.

0.6.1.3 Modélisation multi-agents

La modélisation multi-agent permet de conceptualiser la ou les questions que nous nous posons en définissant clairement les processus et scénarios grâce à un langage clair et précis, créant un véritable laboratoire virtuel. Sa phase de construction est aussi importante que la phase d'exploration. La construction permet de révéler des trous dans la connaissance qui peuvent nous être apportés par des entretiens avec les acteurs ou la littérature. Quand ces connaissances n'existent pas, nous devons alors faire des hypothèses que nous pouvons explicitement décrire, notamment lorsque le modélisateur adopte le protocole ODD+D. Nous pouvons alors définir un ensemble de scénarios et d'indicateurs permettant de comparer les sorties et de comprendre l'effet des scénarios. Le développement du modèle et la structure de la modélisation multi-agent amènent rapidement à une inflation de la taille du modèle, du nombre de scénarios et de paramètres à suivre. Il devient alors quasiment impossible de comprendre ce qu'il s'y passe. La définition et le choix des scénarios doit se faire en prenant en compte l'explosion rapide de la complexité des modèles.

0.6.2 Sur le concept de menaces

Les menaces sont une nouvelle façon d'aborder la question de la gestion de ressources naturelles, habituellement organisée autour de "ressources" ou de "biens". Ces menaces peuvent mener à des actions collectives qui n'existeraient pas sans cela, voire aboutir à la création de communautés intéressées à faire face à cette menace : dans le cas de l'étang de Thau, en temps normal, les ostréiculteurs font la guerre sur les prix, alors qu'en temps de crise, ils se regroupent et s'unissent. La perception d'une menace peut expliquer la création et l'existence d'un groupe ou d'une institution et permet de mieux comprendre les actions collectives engagées, ou les règles établies.

Plusieurs aspects de ce concept méritent d'être explorés plus avant. La typologie a été développée en se focalisant sur les présentes études de cas. L'approche pourrait être confirmée par l'étude de nouveaux cas. Le caractère dynamique des menaces n'a pas été abordé. La mise en place de mesures par un acteur ou un groupe d'acteurs a potentiellement des répercussions internes comme externes au groupe. Il est nécessaire d'étudier le transfert qui est ainsi opéré. L'évaluation des menaces n'a pas été abordée dans la thèse. Il serait intéressant d'étudier la possibilité d'introduire une fonction d'évaluation des menaces couplées aux solutions apportées, ce qui permettrait de les comparer.

0.6.3 Sur l'information pour la gestion de ressources naturelles

Menaces Les études de cas et le modèle nous ont permis d'explorer les liens entre les menaces et le partage de l'information dans le cadre de la gestion de ressources naturelles et plus particulièrement de l'ostréiculture.

Dans le cas d'une menace publique, les acteurs peuvent utiliser le partage de l'information pour gagner de l'influence auprès d'autres acteurs. Ainsi, les ostréiculteurs des bassins ayant développé des EMS ont-ils gagné une grande influence. Les Français ont gagné une information plus précise, mais l'information n'émane pas d'eux et l'artéfact ne provient d'une volonté des ostréiculteurs.

Dans le cas d'une menace privée, le partage de l'information peut être lié à un besoin d'apprentissage. Dans le modèle, nous avons testé la variable de l'apprentissage de dynamiques environnementales ayant un impact important sur les résultats des agents (des ostréiculteurs). Les résultats du modèle indiquent que la simple existence d'un système permettant un partage rapide d'expériences n'implique pas une connaissance parfaite de la dynamique environnementale ni des changements de pratiques permettant une profonde prise en compte de la menace. Cet effet peut être lié en partie au nombre limité d'options à disposition des agents.

Observations générales La participation à l'élaboration d'un système de gestion partagé comme dans le cas australien montre que cela peut être un excellent moyen de faire évoluer, voire converger, les modèles mentaux. La partie de la création paraît donc fondamentale, et l'implication des acteurs paraît modifier les conséquences de l'existence du système. L'utilisation peut se révéler multiple car ces systèmes peuvent toucher plusieurs catégories distinctes d'utilisateurs.

Malgré tout, la simple existence d'un artéfact ne garantit pas qu'il sera utile ni utilisé. Ainsi les ostréiculteurs de la Hawkesbury River (Australie) avaient-ils créé et utilisé un EMS qui ne les a pas protégé des effets d'un virus non prévu. La méconnaissance de l'outil OmegaThau par les ostréiculteurs français en est un autre exemple. Les résultats du modèle montrent que l'existence d'un réseau ou d'outils de partage de l'information permettent une meilleure appréhension des dynamiques environnementales par les acteurs mais que le cumul de ces multiples possibilités de partage ne créent pas d'amélioration forte des pratiques et des croyances.

0.7 Conclusion

Dans cette thèse, nous nous sommes demandé si et comment la mise en place d'artéfacts d'information permettait de faire face à des menaces dans des cas de gestion collective de ressources naturelles. Pour cela, nous avons étudié deux cas d'étude centrés autour de l'ostréiculture, une profession d'acteurs agissant dans des espaces ouverts, les estuaires, et qui dépendent d'une ressource, l'eau, dont la qualité n'est pas la résultante de leurs actions.

L'étude de ces cas et des artéfacts mis en place nous a mené à identifier la notion de menaces et à développer le cadre $\langle \mathcal{A}, \mathcal{C}, I, D, E \rangle$ qui permet de circonscrire une menace subjective pour un groupe d'acteurs.

La méthode que nous avons adoptée a consisté à aborder notre question de plusieurs manières. Nous avons commencé par une approche qualitative, mêlant une analyse de plusieurs terrains grâce au cadre SES qui nous a guidé dans l'exploration et au cadre ENCORE qui nous a fourni des dimensions d'évaluation pour comparer les cas, en présence ou non d'artéfacts. Ensuite, nous avons développé un modèle multi-agent que nous avons simulé pour observer et maîtriser de façon fine les conséquences possibles de scénarios de partage d'information.

Les cas d'étude ont révélé que la réponse à la question initiale n'est pas univoque ni simple. Dans un cas, les effets de l'artéfact sont limités à une meilleure connaissance de certains éléments comme les flux bactériologiques ; dans l'autre, les effets vont nettement plus loin, allant jusqu'à la volonté de créer des institutions propres à l'ostréiculture et à légitimer certains acteurs comme utilisateurs et garants d'une ressource, ici, l'eau. Le processus de création de l'artéfact doit être soigneusement étudié si son impact doit dépasser la simple accumulation de connaissances.

Chapter 1

Introduction

1.1 Natural resources management

Natural resources are under great stress due to climate change linked to an increasing human population and activity. Planetary boundaries have been assessed and crossed on several dimensions (Steffen et al., 2015). Deforestation of tropical forests is happening at a sustained rate of 8 M hectares per year since at least 1990 (Achard et al., 2014). Fish stock is being overharvested in the Mediterranean (Vasilakopoulos et al., 2014) and efforts need to be sustained to rebuild fisheries (Worm et al., 2009), which is feasible, as fishermen managed to do in Northeastern Atlantic Ocean (Fernandes and Cook, 2013). Global solutions have yet to be found, for instance in forums such as COP21, held in Paris in 2015.

The tragedy of the commons predicts exhaustion of open-access resources (Hardin, 1968), proposing private or public management as the only solutions. An important body of work has shown that local populations of actors can craft emergent management rules and principles for a sustainable management of resources they deal with (*e.g.* Acheson, 1975; Ostrom, 1990; Lansing, 2009; Cox et al., 2010). Protection of areas may be done more easily with local actors participation, such as in National Parks in Norway (Risvoll et al., 2014); Nepalese users of the Rupa Lake found a way to reverse the tragedy deemed to hit the lake (Chaudhary et al., 2015).

Interdisciplinary studies on Natural Resources Management (NRM) are increasingly advocated for (*e.g.* Bhaskar et al., 2010), emphasizing on the tight connection between resources, users of resources and a set of rules framing how users may exploit the resource (Binder et al., 2013). The importance of taking advantage of local users knowledge in management of their environment is recognized and used (Rommetveit et al., 2010). In those context of high uncertainty and importance of decisions, questions go beyond simple technical or scientific knowledge and postnormal sciences need to be applied (Funtowicz and Ravetz, 2003; Bray and von Storch, 1999) encompassing potential

conflicts (Adams et al., 2003) or diversity of mental models (Castillo Brieva, 2013). Reflexivity over local environment can be enhanced using participatory methods involving local stakeholders, for instance through role-playing games (Barreteau et al., 2007), agent-based modeling (Bousquet and Le Page, 2004), or co-planning (Daniell, 2012).

1.2 Information and information sharing

We currently live in a world loaded with information. Information is ubiquitous, used in an immense variety of contexts, from local and specific (local public transportation timetable) to global and far-reaching (Wikipedia). Battles between transparency and confidentiality are advocated and supported by different groups: from open-data and open-software movements to copyright tenants who want to protect information costly to produce. We have entered an information age (Castells, 2011), a knowledge democracy where “both dominant and non-dominant actors have equal access and ability to put knowledge forward in the process of solving societal problems” (Bunders et al., 2010, p.125).

Information existence and availability led to improvements such as African farmers getting to know market prices and being less prone to be tricked by buyers (Aker, 2008). Collective action projects such as openStreetMaps in Haiti¹ - users around the world created an accurate map of Haiti’s roads in a few days right after the 2010 earthquake for all, especially humanitarian workers, to use - show a capacity of information to be produced and used quickly, building upon technological means and engaged users.

Production of science, data as much as knowledge, is increasingly participatory, thanks to the use of information technologies, for instance through distributed computing². This phenomenon is not new. Star and Griesemer (1989) give the example of a form used in 1907-39 by a zoological garden in the United States that was to be filled by different populations in order to widen information gathering. Now, the availability of modern information and communication technologies boosts these areas of knowledge production almost anywhere and at any time.

With these different examples, we could hypothesize that the more information we have, within physical limits of our cognitive possibilities, the more we know about the surrounding world and the better and more sustainably we can live in it.

What can be the impact of information availability and sharing for actors that have to interact with a renewable natural resource? This question is vast and deserves a qualified and contextualized answer. In this thesis, I explore

¹http://wiki.openstreetmap.org/wiki/WikiProject_Haiti/Earthquake_map_resources

²For instance, a project on protein folding: <http://folding.stanford.edu/home/>

this subject at the level of local systems and investigate the idea according to which more information leads to better resource management.

1.3 Purpose and problem of the thesis

This thesis is interdisciplinary and uses computer science, through modeling, as a way to synthesize knowledge acquired using strengths of various fields such as economics, geography, sociology, political sciences or decision aid. The thesis is eventually meant to better formulate and understand issues related to people actions and stakes in fundamentally uncertain systems linking humans and their environment. In those systems, actors need to make decisions based on norms, beliefs and knowledge. These decisions affect others around them.

In a seminal paper discussing globalization of social-ecological research, [Young et al. \(2006\)](#) suggest that the revolution of information technologies, along with the rise of mega-cities and the demand for hydrocarbons, is one of the key trends that could impact the management of natural resources. This impact may be measured in terms of vulnerability, resilience, or adaptation.

As evoked above, natural resources are under pressure and have to face multiple issues such as exhaustion, misuse, competition or pollution. Actors devised a vast variety of ways to deal with those pressures over a period of centuries. A recent trend in [NRM](#) is to implement artifacts actors can share information through. Can those artifacts help actors manage resources by making decision that would be better for them and for the resource in general?

Formulated in those terms the question is not precise enough. [NRM](#) is a vast field that covers resources of intrinsically different nature. A single thesis is not enough to cover all these different types and [Ostrom \(2007a\)](#) warns against panaceas (one-size-fits-all solutions). A contextual focus was thus required ([Edwards and Steins, 1999](#); [Castillo et al., 2011](#)). An important amount of research has been conducted in cases of resources where actors are homogeneous and tap a relatively bounded resource, typically common-pool resources ([Cox et al., 2010](#)).

In this thesis, we decided to focus on intrinsically open environments where various actors have different roles, impacts and goals interact. These situations are particularly interesting when studying artifacts that may be considered at the interface between heterogeneous actors and as tools for collection action. Water in coastal catchment is such a resource: the environment is open and actors have various goals, beliefs, practices and relation to the resource. In such environments, an activity with high demands on water quality may be conducted, like oyster farming. These actors are the most sensitive actors regarding water quality in estuaries of coastal catchment. They act in fundamentally open environments due to the high impact of catchment actors and inhabitants' practices. The case of oyster farming, placed in the ecology of coastal catchments seemed a perfect option for the intended study.

This option was motivated by a second element: in the chosen cases, more or less technology-laden information sharing artifacts have been developed as tools to help manage the resources. These artifacts proved to be destined at getting information to tackle threats (such as pollution, exhaustion or free-riding) actors need to collectively face and at helping them make better and more informed decisions.

This context led me to frame the main question of the thesis as follows:

*How can information sharing help actors interacting together
and with natural resources to face threats?*

To provide an answer to this complex question, I consider several subquestions:

- There are several types of threats. What are those threats and what characterizes them?
- What are the stakes linking the different types of threats and information sharing artifacts?
- Can information sharing artifacts help actors to improve their businesses?
- Can information sharing artifacts help actors manage resources they interact with?
- Reversely, can information sharing artifacts be of no use or even harmful?

In the thesis, I use a descriptive approach through the direct study of cases and an agent-based model. This approach does not allow for general demonstrations of normative theorems starting with “for all ...” that can only be obtained using a reasoning based on a normative or an axiomatic approach. The method allows for a refutation of such generalities by finding counter examples of such theorems, *i.e.* conclusions starting with “there exists ...”. Case studies allow a detailed exploration of specific and contextualized artifacts and their effects may be observed directly or through interviews. Agent-based modeling opens the way to fine and mastered exploring of a situation inspired from the case studies and focused on information sharing artifacts.

1.4 Structure of the thesis

In order to explore the listed questions, I start by presenting conceptual elements in Part I. In Chapter 2, I begin by introducing the usual vision on collective NRM that draws upon an identification of good and resource types to frame challenges for actors possibly as social dilemmas. I also describe a framework used to depict coupled human and natural systems called the

Social-Ecological System (SES) framework (Folke et al., 2005; Ostrom, 2009). Then, in Chapter 3, I develop the concept of threats for which I propose a characterization, as well as a typology. This concept emerged from the study of information sharing artifacts that actors of the case studies developed. I advocate for the explicit introduction of threats in the SES framework since they are part of a diagnosis of a situation the framework intends to understand, especially when considered from a decision-making perspective. Finally, I delve into the question of information sharing in the context of SESs. I explain the specific challenges information artifacts set up at local levels face and explore the stakes information sharing poses to tackle threats actors face in Chapter 4.

After exposing these elements, I present the methodology that I adopted to investigate the main questions of the thesis in Part II. I predominantly used two approaches. The first one (Chapter 5) is a case study investigation that consisted of interviews, meetings, participatory observation and study of actual artifacts. The second one (Chapter 6) is agent-based modeling, a method increasingly used to study social complexity (Edmonds and Meyer, 2013b).

As explained in the previous section, a contextual focus is important in the study of NRM. I present those cases in Part III. Before considering the actual cases, I begin by discussing in Chapter 7 the ecology of oyster farming in general: the environment in which growers act, the biology and ecology of oysters, as well as a general presentation of practices. I also discuss consequences of change in scale for the analysis of SESs. In Chapter 8, I delve into the two actual cases that I studied in New South Wales (NSW), Australia and Thau Lagoon, France. I present in detail the local environments actors evolve in, and information sharing artifacts that they developed, using the SES framework as a guideline. Finally, in Chapter 9, I frame the resources and threats oyster farmers deal with using the conceptual elements developed in Part I.

Using the previous parts, I present results regarding information sharing roles for actors in two different threat cases in Part IV. In Chapter 10, I draw upon the cases and artifacts that actors developed to tackle general water quality issues and in Chapter 11, I propose and analyze an agent-based model developed on a pressing issue for oyster farmers, a virulent virus that heavily harms oysters.

I finish the thesis with a discussion (Chapter 12) and a conclusion (Chapter 13).

1.5 A tale in the thesis

Before entering into the body of the thesis, I tell an illustrative story intended as an archetypal situation that shows how actors, the environment, rules and institutions are interwoven in a complex manner.

I describe a simplified version of such an environment which articulates the

main issues that actors face and the resource(s) they are in relation with. The description focuses on a type of users of a resource. The overall goal of this section is to present a situation that I will use as a running virtual example and refer to throughout Part I to illustrate more clearly the presented ideas, as [Hardin \(1968\)](#) did in his seminal paper. This situation is inspired by real cases. The global context is presented here as a whole and will be developed further when necessary in the following chapters.

A village located on a sunny coastline. An important community of fishermen lives and work in the village. For a long time already, fishermen have been using their boats, fishing nearby and are famous for being able to find a specific very appreciated fish that is sold up to the capital of the country. They store their boat in a harbor, located in a naturally protected bay.

Fishermen are organized in a fishery where they devise rules, train newcomers, even though most fishermen are there because fishing is a family affair. The fishery is in charge of maintaining the harbor docks, of deciding over quotas and allocating fishing areas, which is mostly done using a random draw. Conflicts have been under control for a long time but the local situation is changing.

Thanks to their privileged location, the village, nearby beaches and the surrounding region are highly attractive to tourists. Population doubles during summer, which creates an important flow of money for the village as well as a few issues such as water treatment. Leisure boating and fishing is a popular activity, so is jet-skiing or windsurfing. This demand creates conflicts with local fishermen, who have more difficulties in practicing their activity, even though tourists enable them to sell much more fish than during the rest of the year. On the shore, they are in competition with tourism infrastructure developers that push for the building of marinas, hotels and privatization of beaches. There is also a demand for tourism boats storage in the harbor.

The increasing demand for fish entices fishermen to fish a little more, creating an important pressure on the fish stock, and in parallel, a drop in fish prices. This situation is aggravated by tourists who fish without properly knowing fishing rules and areas, or even release black water directly in the water instead of using the water pumps in the harbor to save some money, resulting in deterioration of water quality.

The local government is in charge of general development (and control of development) in areas such as water and urbanization, but it is known to be quite weak and corrupt: urbanization project can be facilitated with a little bribe and water treatment could be handled better with proper investment. Sewage treatment plants are not very efficient and water is released in pipes directly in the sea not too far from the coastline. The word has it that a few tourists were poisoned by a dubious fish. The investigation did not go too far, but internally concerns were risen about possible contamination of the local ecosystem.

Fishermen also face two other issues. The first one is linked to the presence

of foreign industrial boats that use heavy machinery and deplete local stocks. The second is linked to a recent observation that the very appreciated local fish is an indirect victim of water eutrophication: new algae are replacing traditional vegetation in which this fish species spawns its offspring.

In the following chapter, we will follow Bob, a fisherman, whose life is actually quite complex.

Part I

State of the Art



Chapter 2

Resources, Dilemmas and Social-Ecological Systems

Renewable natural resources that produce goods extractable by people are subject to pressures. They are harvested by multiple and possibly uncoordinated actors following various goals and having different interests. How to guarantee a sustainable use of the resource while favoring equity is one of the key questions in [Natural Resources Management \(NRM\)](#)? Public or private management are possible ways to manage natural goods or resources ([Hardin, 1968](#)). Studies of real coupled human and natural systems have revealed that other methods exist, such as common management. [Ostrom \(1990\)](#) has shown that in some situations local actors found ways to collectively create institutions that allow them to maintain a sustainable use of a resource over centuries. With the intention of clarifying the different types of management linked to key properties of resources, [Ostrom et al. \(1994\)](#) propose a typology of goods and resources actors may use, and [Schlager and Ostrom \(1992\)](#) specify bundles of rights users have access to. I built part of the analysis of this thesis on these notions presented in this chapter.

I focus on systems where actors are striving to grow oysters in estuaries. These actors are confronted with management of various natural resources they need for their activity. Thus, I first present the typology of goods and resources, as well as actors' property rights mentioned above that I will use to frame and analyze the case studies. Then, I expose a conceptualization of the key issues actors extracting goods produced by resources face: social dilemmas. Subsequently, I recall necessary principles of institution design for successful common resource management as well as the asymmetric commons situation that will be useful to analyze the case studies. Finally, I present a framework that enables a diagnosis of systems where humans interact with a collective resource and that I will use throughout the thesis: the [Social-Ecological System \(SES\)](#) framework ([Folke et al., 2005](#)).

2.1 Resources and users

2.1.1 Goods and resources

In the narrative of the tragedy of the commons, [Hardin \(1968\)](#) tells the story of herders leading their herd to a pasture. They all face a choice: increasing the size of their herd or keeping it the same size. Since they are “rational” (*i.e.* short term profit maximizing) agents, they all choose to increase their herd size, resulting in pasture exhaustion and in the long run, bankruptcy of the herders. Two solutions are then given for the pasture management: privatization (all herders manage their own piece of land), or nationalization (an all-mighty ruler decides over pasture management, taking into account the resource interests). This story is a narrative of a simple system. An input leads to easily predictable outcomes.

Discovering that many natural resources have been managed in a sustainable way for centuries or even millenia by people without using either private or public solutions, [NRM](#) scholars, like Elinor Ostrom, have shown that several other ways existed for managing a good or a resource. For a given good, it is important to pay attention to two main properties that define its nature: subtractability and exclusivity ([Ostrom et al., 1994](#)). “The first attribute is that the benefits consumed by one individual subtract from the benefits available to others. The second attribute is that it is very costly to exclude individuals from using the flow of benefits either through physical barriers or legal instruments. Both attributes vary across a range” ([Hess and Ostrom, 2003](#), p.119).

Four broad types of goods can thus be defined: public, club, private, and a [Common-pool resource \(CPR\)](#) (Table 2.1). Of course, there are other variables and some goods can be in certain categories under some conditions and in another under other conditions. For instance, even though a public road is a public good, since there is low exclusivity and subtractability, the latter property can turn to high subtractability at peak hours, making the good more akin to a [CPR](#), or a club-good if a toll is set up.

Except for private goods, other goods are shared among several people and are usually managed according to institutions, which can be more or less formal. “Institutions are human-constructed constraints or opportunities within which individual choices take place and which shape the consequences of their choices” ([McGinnis, 2011](#), p.170). They can range from mere norms to sets of people with legal powers.

Let us take a look back at our original example¹. Bob the fisherman has to deal with numerous goods and resources of different types. Bob owns his boat and nets that he uses to fish. He docks his boat along the piers reserved

¹In the rest of the text, I emphasize the example of Bob the fisherman to make it easier for the reader to distinguish between theoretical elements and the example. See Section 1.5, p.5, for the whole story.

Table 2.1: Typology of goods and resources ([Ostrom et al., 1994](#)).

	Subtractability	
	Low	High
Exclusivity	Low Public good	High Common-pool resource
	High Club good	Private good

for fishermen. These docks are an example of club goods: Bob has to pay a fee to use the docks of the harbor whose use is restricted to fishing boats. These fees are added to State subsidies and allow the harbor authorities to maintain the docks and the rest of the harbor in a well-functioning state. The fish resource out of which Bob earns a living is a typical CPR. After unloading his boat, Bob drives to the market, a boundary institution where fishermen and buyers interact, using his private truck on public roads. The different goods and resources Bob interacts with are all necessary for his activity. They are managed by different institutions. He has to take care of his private belongings. The boat, nets and other technologies, which are private goods and used by Bob to fish are regulated by the local fishing institution. This institution devises rules to ensure sustainability of local fish stock by defining rules for technologies used as well as fishing periods and locations. It also deals with occasional conflicts that arise among fishermen. This institution has a strong legitimacy since it has existed for a long time and is composed of fishermen themselves. For his activity as a fisherman, Bob has to interact with many different types of goods, which are under varied property regimes (Section 2.1.2).

This whole situation, featuring a combination of different types of goods and resources, is actually a description of a resource system, part of a global system called a social-ecological system, a framework that will be introduced in Section 2.3. Besides interacting with goods of all types, Bob interacts with other people who play different roles and have different property rights to the resources.

2.1.2 Users and property rights

There are different types of users defined according to how they are allowed to interact with the resource. These types were mostly defined on the study of CPRs and are valid mostly when there is subtractability. According to R. John (cited in [Schlager and Ostrom, 1992](#)), a property right is an enforceable authority to undertake particular actions in a specific domain. These property rights open different privileges. In the context of NRM, five bundles of rights are defined: access (right to enter an area and enjoy non subtractive benefits), extract (right to obtain resource units), management (right to regulate internal use patterns and transform the resource), exclusion (right to determine who

Table 2.2: Types of users and associated property rights. These levels exist for a complex resource such as a CPR from which one can extract units (Adapted from Schlager and Ostrom, 1992; Hess and Ostrom, 2003).

	Access	Extract	Manage	Exclude	Alienate	Example
Owner	✗	✗	✗	✗	✗	?
Proprietor	✗	✗	✗	✗		Fishermen board
Claimant	✗	✗	✗			Fishermen assembly
Authorized user	✗	✗				Fisherman
Authorized entrant	✗					Recreational boater

will have access rights and withdraw or transfer rights), and alienation (right to sell or lease management and exclusion rights). Table 2.2 illustrates these rights with examples.

As a licensed fisherman, Bob has access and extraction rights. Everyone has access rights and tourists can ask for an authorization to fish (temporally limited extraction rights) to authorities who have exclusion rights. Traditionally, management of the resource is left to the fishermen and their institution with the help of public authorities who enforce rules valid at a larger level. Exclusion is left to a subset of fishermen and takes place in the institution. They are elected every year and deal with conflicts among fishermen and try to help fishermen interact with other types of actors.

Interactions among users are multiple and take various shapes. One of the main difficulties in renewable resources management lies in the existence of conflicts between users, usually linked to a discrepancy between short-term individual interest and long-term collective interest. These difficulties can be represented as social dilemmas.

2.2 Social dilemmas

In this section, I present social dilemmas, a theoretical situation that enables to capture the core of NRM issues: the discrepancy between short term individual interest and long term collective interest. After presenting an archetypal situation of social dilemma between two, then N , actors, I describe the necessary principles for CPR management found by Ostrom (1990) that allow actors to collectively escape social dilemmas. Finally, I present the question of asymmetry in resources management that actors in the case studies of this thesis face.

Table 2.3: Prisoner’s dilemma payoff matrix: $T > R > P > S$. Column (row) player gets first (second) payoff.

Strategy	Cooperation	Defection
Cooperation	R, R	S, T
Defection	T, S	P, P

2.2.1 Social dilemmas and what to do about them

Social dilemmas are situations in which “two or more participants must each choose between following their own immediate interests, or the common interests of all participants. For each participant, choosing the ‘selfish’ option is immediately advantageous, *whatever* the other participants do, but if enough participants take this option, *all* end up worse off than if enough had made the ‘altruistic’ or ‘cooperative’ choice” (Gotts et al., 2003, p.3). Elster (1989) argues that in these situations lie the tension between what Adam Smith called the *homo economicus*, who listens solely to his own private interests, and what Emile Durkheim called the *homo socialius*, who acts purely as a member of a social group following collective norms, a tension that lies within each of us.

The most famous dilemma is probably the prisoner’s dilemma (Flood, 1958; Poundstone, 2011). In a prisoner’s dilemma, two isolated players are charged with some accusation. They are given a choice (strategies) by the police: to cooperate or to defect. Table 2.3 shows the payoff matrix of this situation. There are four possible payoffs that depend on players’ choices. When both cooperate, they get the reward (R). When both defect, they get the punishment (P). When one cooperates and the other defects, the cooperator gets the sucker’s payoff (S) and the defector the temptation one (T). The difficulty of the situation lies in the fact that, when simply presented under this form, defection is a winning strategy for rational players, leading to a collective outcome that is worse than when both cooperate.

The basic result is that even for two people, rational behavior (the dominant strategy) is at odds with collective, and thus personal interest. Presented under this form, this game seems as depressing and inextricable as the tragedy of the commons. However, by looking at actual human behavior and studying resource management, one can have a sense that this situation is not doomed. Several ways out can be imagined. First, communication and agreement can make both prisoners realize that cooperation leads to a better social outcome. Second, it is possible to set up institutions to change the payoff matrix, for instance by making defection punished (financially or socially) and thus less attractive. Another solution that has been devised to escape the dilemma is through the iterated prisoner’s dilemma. Axelrod and Hamilton (1981) conducted a famous experiment that determined that the best strategy in a series of prisoner’s dilemma situations is called tit-for-tat: starting with coopera-

tion and doing what the other player did at the previous round. This type of strategy can be called *conditional cooperation* where player cooperate as long as they are sure that the other player will. This strategy has been observed in case studies (Rustagi et al., 2010) and in experiments (Fischbacher et al., 2001; Kocher et al., 2008) with two or more players. This behavior is coherent with what is known in evolutionary biology under the name reciprocal altruism, observed inter and intra species, from bacteria to humans (Trivers, 2006). This property is seen as one of the keystone of the theory of evolution which entices cooperation with non kins and as the one that allowed *homo sapiens* to successfully colonize the planet (Marean, 2015).

The tragedy of the commons described in Section 2.1.1 is another example of social dilemma with many players facing a dilemma between the long run common interest (preserving the pasture), and the short term individual interest (increasing herd size). Two main behaviors are defined here: *cooperation* and *free-riding*. A free-rider is someone who benefits from a low excludable resource without financing it. Examples of free-riding could be: not paying taxes, using an irrigation system without participating in renovation works, defecting in the prisoner's dilemma.

There are ways to minimize the negative impact of temptation to free-ride. Firstly, people live in communities within which they share social bonds of different types. If a defection can be easily spotted and the defector easily identified, then it is not very likely that the actor will choose to defect. This is the reason why a lot of rules are defined in such terms that it is easy to see whether the person has broken the rule: "Seeing somebody in the wrong spot at the wrong time with the wrong gear will be a clear violation of institutional arrangements" (Janssen, 2013, p.1). Secondly, norms come with education and culture and are an important factor (Elster, 1989). While it may be tempting to leave litter in a park, an internal norm could tell the person that it is something wrong to do and free-riding would actually be a matter of moral choice (Ostrom, 2014). Norms "are sustained by the feelings of embarrassment, anxiety, guilt and shame that a person suffers at the prospect of violating them" (Elster, 1989, p.100). Thirdly, it has been observed that people are prone to engage costly monitoring, enforcement and punishment to prevent free-riding, thereby ensuring conditional cooperation (Janssen et al., 2010, 2012; Rustagi et al., 2010). Being aware of several unpunished rule infringement could lead people to believe that they are "suckers" (the position the player is in when he chooses to cooperate while the other defects) and thus entice them to break the rule as well.

Our fictional character Bob faces social dilemmas. Regarding his fishing activity, he faces a commons dilemma since he could be inclined towards fishing with more efficient techniques or catching smaller fish than allowed, to generate more income. This situation applies to all fishermen of the village. This is why, as in the example of the Maine lobster fishery where fishermen mark certain types of lobsters (Acheson, 1975, 2003), the fishing institution has established

Table 2.4: CPR design principles (Adapted from Cox et al., 2010, Table 3).

Design principle	Definition
Clearly defined boundaries - actors	Individuals or households who have rights to withdraw resource units from the CPR must be clearly defined
Clearly defined boundaries - resource	The boundaries of the CPR must be well defined
Congruence between appropriation and provision rules and local conditions	Appropriation rules restricting time, place, technology, and/or quantity of resource units are related to local conditions
Congruence between appropriation and provision rules and local conditions	Benefits obtained by users from a CPR, as determined by appropriation rules, are proportional to the amount of inputs required in the form of labor, material, or money, as determined by provision rules
Collective-choice arrangements	Most individuals affected by the operational rules can participate in modifying the operational rules
Monitoring - presence	Monitors are present and actively audit CPR conditions and appropriator behavior
Monitoring - accountability	Monitors are accountable to or are the appropriators
Graduated sanctions	Appropriators who violate operational rules are likely to be assessed graduated sanctions (depending on the seriousness and context of the offense) by other appropriators, officials accountable to these appropriators, or both
Conflict-resolution mechanisms	Appropriators and their officials have rapid access to low-cost local arenas to resolve conflicts among appropriators or between appropriators and officials
Minimal recognition of rights to organize	The rights of appropriators to devise their own institutions are not challenged by external governmental authorities
Nested enterprises	Appropriation, provision, monitoring, enforcement, conflict resolution, and governance activities are organized in multiple layers of nested enterprises

minimum size rules and thus properties on nets legal to use. Buyers at the market are also compelled to check whether the fish being sold meets this size condition. Since the community is not that big, repetitive lack of compliance to this accepted rule, or norm, could lead to social issues for the fisherman implied. Since errors can occur, if this non compliance happens, the fisherman is not ostracized: a gradual sanctioning system is applied.

2.2.2 Common-pool resources management design principles

As a focal type of resource in NRM, CPRs have been under close look and studied in-depth. The halieutic resource that Bob and the community of fishermen extract fish from is a CPR since it is possible to extract units (it is subtractable) and it is difficult to exclude someone from extracting fish (it is

non excludable). Other classical examples of resources that can be considered CPRs are collective irrigation networks, common forests, or common land.

These resources are typical resources that fall under the realm of the tragedy of the commons. Initially proposed solutions consider public or private regulations as the only management options (Hardin, 1968). However, it has been proved that under certain conditions, local actors managed to devise adapted ways to manage a resource that is necessary to all and used by all in a sustainable way. Ostrom (1990), in her seminal book *Governing the commons*, has proposed 8 design principles that have proved robust over time after scholars studies numerous case studies (Table 2.4). 20 years after publication of the book, Cox et al. (2010) review 91 case studies and confirm the strength of the principles.

These principles put an important amount of trust on local users of resources postulating that they are those who most regularly interact with it and have a collective interest in maintaining it in the long run. Thus, those actors have a strong interest in setting up institutions that guarantee a sustainable use of the resource they manage. These institutions may create conditions so that personal short term and collective long term interests are aligned, subsequently favoring cooperation and sustainability. an important reward behind modifying the structure of the CPR extraction and participation payoffs. Actors may successfully build structures where the personal and collective interests are aligned if they follow the design principles.

2.2.3 Asymmetric commons

Let us say Bob faces problems coming from the upper catchment. As a fisherman, he is very concerned with water quality, a public good, especially in summer when population doubles. City effluents are supposed to be treated in sewage treatment plants, but these plants are old and hardly stand the flow. In this situation, we can identify upstream actors (city dwellers and tourists) as a loose category of users and downstream actors (fishermen). In this section, I focus on this type of upstream - downstream situations.

Upstream - downstream situations are such that there is a physical flow, like water, running from upstream actors to downstream ones. Downstream actors are locked and have to undergo upstream users choices. Solutions based only on individual and selfish choices of upstream actors are likely to affect negatively downstream ones. An interesting question is to investigate ways to close the loop by creating a feedback, as illustrated in Figure 2.1. Such feedback can consist in money (as in Jack, 2009), other type of physical drawback (such as pests in Lansing, 1991), shared values and norms, or information. This last type of feedback will be of particular interest in this thesis. The studies that I found involve homogeneous actors, linked by the same CPR, such as farmers pumping into a running river. This situation can be generalized in more global situations with heterogeneous actors, acting in the same place,

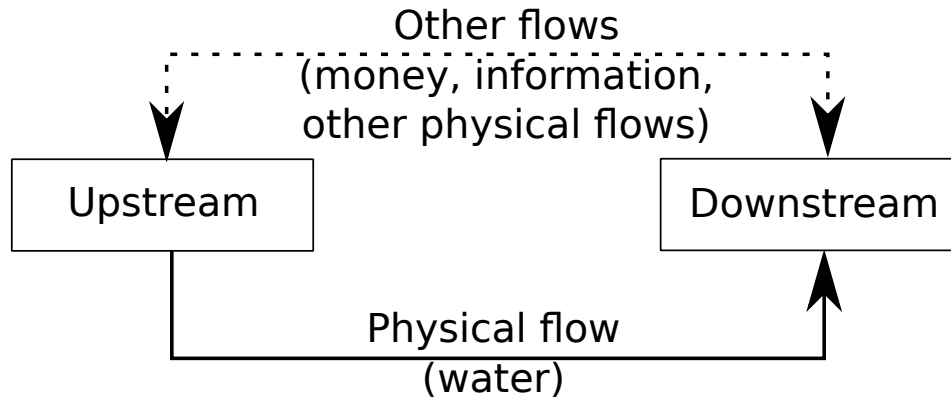


Figure 2.1: Upstream Downstream flows

around different kinds of goods. The case study in this document involve such a situation (Chapter 10).

2.3 The SES framework

After Hardin’s article, the study of the commons was particularly focused on CPR management, in a manner that provided a way out of the private/public dichotomy (Ostrom, 1990) as described in Section 2.2.2. The questions that this field raises are fundamental and can be applied to different situations. Scholars studied interactions between actors and a renewable resource that produces units that can be subtracted (Table 2.1). How do users can prevent exhaustion of the resource they all need? How can they prevent free-riding? How do they implement solid institutions? What are the links they keep with the local resource? In what way is institutions building path-dependent? How can failure be explained?

A step further into NRM made researchers take a step back and look more globally at systems where social and ecological systems interact and for ways to link the two (Berkes and Folke, 1998). This research resulted in the design (Folke et al., 2005; Ostrom, 2007a) and improvement (Ostrom, 2009; McGinnis and Ostrom, 2014) of a broad framework called the Social-Ecological System (SES) framework, illustrated in Figure 2.2 in its current version. Ostrom (2007a) illustrates the framework with Hardin’s model. It shows that Hardin’s metaphor was actually a very specific case in the class of all SESs. In this model, Hardin’s conclusions may be true, but this is not a sufficient reason for undue generalization. Once again, human organizations and interactions with the environment are resisting simple explanations and one-size-fits-all outcomes.

Figure 2.2 is a summary of relationships between broad entities in interac-

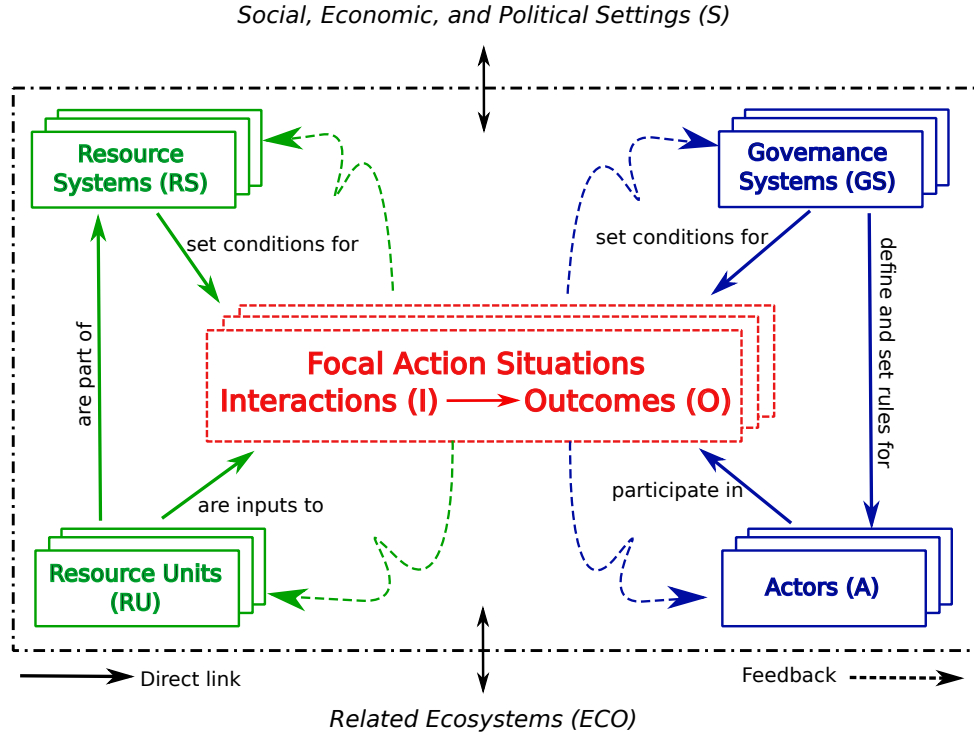


Figure 2.2: The SES framework (McGinnis and Ostrom, 2014)

tion. Each entity can be described using several variables. McGinnis and Ostrom (2014) provide a list of second-tier variables recalled in Table B.1, p.260. A SES is centered around a resource system (RS) (e.g. fish stock, forest, pasture, irrigation system) that produces resource units (RU) (fish, trees, food for cattle, water). The full description of these two entities contains specifications about the size of the system and biological knowledge. SESs involve some actors (A) (Bob and other fishermen, local dwellers, public authorities) and a governance system (GS) where the different institutions actors have to deal with and/or have established are described. Actors can have different types of property rights, from simple use to alienation. Thus, they can share different relations with the RS. Some of these broad entities interact directly with each other: RU are a part of RS, and GS define and set rules for A. They are all interacting in another type of entity called the *action situation* (Ostrom, 2007b). An action situation is a situation where “individuals (acting on their own or as agents of organizations) observe information, select actions, engage in patterns of interaction, and realize outcomes from their interaction.” (McGinnis, 2011, p.173). RS, RU, A, and GS are influencing the action situation, and the action situations influence back to these entities. Action situations are divided in two main parts: interactions and outcomes. In the interaction part of the action situation, there are variables such as processes, conflicts, or common activities

(investment, lobbying, networking ...). Information sharing is one of them. These interactions result in producing outcomes on social (mainly for A) and ecological (for RS and RU) dimensions. These outcomes are the base of the feedbacks.

In [NRM](#), a system description is not complete without paying attention to what is outside of the system. Two main dimensions are defined. The first one describes the general social, economic and political settings (S) the [SES](#) is included in. These dimensions encompass the global situation, located above the [SES](#) that is studied. The second dimension focuses on related ecosystems (ECO) that are linked to the focal [SES](#), through flows in and out the [SES](#), or pollutions (externalities).

This framework has been applied in the literature to a variety of topics regarding common management of resources. Authors use it at different scales, from a single case study to worldwide comparisons. [Risvoll et al. \(2014\)](#) use it to investigate consequences of pastoralists' participation in national parks management in Norway. [Nagendra and Ostrom \(2014\)](#) apply the [SES](#) framework to understand and analyze differences on the evolution of collaboration for the management of several lakes of different sizes and ecological conditions in Bangalore, India. [Gutiérrez et al. \(2011\)](#) employ the framework to compare 130 co-managed fisheries all over the world and, by identifying key variables, they demonstrated that leadership, social capital and incentives promote successful fisheries. The [SES](#) framework provides an opportunity for a clear and precise description of a complex situation where actors with different property-rights over various types of goods are intertwined in a single system.

One can think Bob and his fellow fishermen as the set of actors. But the framework could describe a situation where A goes beyond fishermen, including tourists or city inhabitants. The basic RS is the fish stock, but one can define RS as the whole watershed, which would change ECO variables, multiply possible indicators for outcomes, and make interactions more complex (Chapter 7). It is a matter of choice, and of question one wishes to address: the [SES](#) framework is adapted to clarify the analyst's choices and to allow comparisons (of scales or cases) on a vast set of variables. I use this framework with this idea in mind in the rest of the thesis. In the upstream downstream situation, there could be nested [SESs](#), where upstream and downstream are two [SESs](#), included in a bigger one that encompasses the two systems. Furthermore, the depth in which those interested in studying a [SES](#) needs to be carefully calibrated. There are numerous proposed variables, and some authors propose even more variables, according to their focal point. For instance, [Vogt et al. \(2015\)](#) propose to unpack the "E" in the [SES](#). They provide much more information about the ecological aspects of a [SES](#) that they believe too scarce in the way the [SES](#) framework has been formulated (because of its social sciences background). I make full use of these suggestions when describing in a generic way the RS and RU of the case studies (Chapter 7).

2.4 Conclusion

In this chapter, I presented a first conceptualization of [NRM](#) situations. A proper characterization of goods and resources properties provided a way out of the private/public dichotomy for renewable resources management by introducing common management of resources ([Ostrom, 1990](#); [Ostrom et al., 1994](#)). Studies of actual situations led to unveil an important complexity and variety in ways actors manage the resources they need and use. Actors defined various rights from simple access to right to sell the resource and devised institutions that allowed for sustainable use of resources.

Institutions, regulations and norms exist in the context of [NRM](#) because of a fundamental tension that occurs between short term rational interest and long term collective interest, a situation that is called a social dilemma. The prisoner's dilemma or tragedy of the commons are theoretical instances of social dilemma. Fortunately, [Ostrom \(1990\)](#) suggests ways to manage these situations in the context of common-pool resources by guaranteeing that the 8 design principles recalled in [Table 2.4](#) are verified.

Actors managing collective resources act in social-ecological systems. I presented this framework that will lie at the background of the thesis and structured the exploration of the cases.

Bob is worried. He is convinced that water quality is getting poorer. It is very likely that this situation comes from poor handling of water effluents coming from the city. He believes that fish population is decreasing since he catches less fish than before, even though he is not sure how much or if this is cyclical or due to climate change. He does not know for sure, but suspects that the flow of tourists fishing for leisure is detrimental to the fish stock since they probably do not respect the rule that fixes a minimum size of caught fish (there is almost no monitoring from authorities).

I call threats the different problems Bob faces. The goods and resources typology as well as the [SES](#) framework presented in this chapter do not make an obvious place for these threats. Even though the typology enables an identification of resources characteristics, an effective typology of threats faced by groups of actors and how their characteristics may influence and help collective decision-making or information-seeking is lacking.

How are these threats (exhaustion of fish stock, pollution of water, climate change) of different nature? How one should deal with all these different threats? What is the influence of information-sharing on actors and their environment? These questions will be the topic of the rest of the thesis, starting with the following chapter that defines precisely this notion and creates a typology of threats in the context of [NRM](#).

Chapter 3

Threats for Goods

The questions raised at the end of the previous chapter are important issues to explore in order to understand evolution of resources management, as we will see in this chapter and in Part III. Actors of SESs have to collectively make decisions, devise rules, create institutions to sustainably manage resources that are necessary for all. The difficulty underlying NRM is linked to the existence of collective threats, that all have to face and deal with, and that actors have to solve or understand together. To my knowledge, there is no precise description of threats. What are the nature of threats faced by actors? How can we create a typology of threats? How is this typology helpful to identify ways to tackle these threats?

In this chapter, I formalize the concept of threat that I will refer to throughout the thesis. I make the case that these threats of various nature and types are at the core of understanding relations between users of a resource. They are also key to the implementation of information sharing artifacts, as I will show in Chapter 4.

First, I define the concept, then I differentiate threats from similar concepts such as risk, uncertainty, or hazard, and illustrate threats with examples taken from the literature. After, I describe two key properties that will enable identification of different types of threats: internality and excludability. Then, I show that goods of all types can be part of threats of all types. Finally, I make the case for the addition of this concept to the SES framework, showing that a case diagnosis cannot oversee these key elements.

3.1 Why a threat?

In addition to the numerous types of goods and associated property rights that Bob has to deal with everyday, he has to take into account threats that these goods face to make his day-to-day or long term decisions. He could lose his boat in a tsunami, or simply due to poor maintenance, fish stock could be depleted because of pollution or overharvesting.

Difficulties in [NRM](#) are linked to multiple elements. [Hardin \(1968\)](#) pointed out free-riding, overharvesting and eventually exhaustion, all threats for open-access resources and actors who use them. These threats to the resource force actors that want to manage resources they use to devise ways to avoid losing access or the possibility of exploiting the resource. However, threats that resources used collectively by actors face are not defined.

A large body of literature emphasizes particular threats associated with [CPRs](#) without using such a conceptualization. In [Section 2.2.2](#), I have exposed [CPR](#) necessary design principles as ways out of these threats that actors of [CPRs](#) face ([Cox et al., 2010](#)). However, some threats are not directly, or uniquely, linked to the decisions and infrastructure of actors of systems with clearly identifiable actors and boundaries.

A precise definition, characterization and typology of threats can help to gain a deeper view of actions available to actors and relate these to different types of goods that actors use for their activities. This will be the topic of this chapter. First, I define threats. Then, I focus on similar concepts such as risk, uncertainty, or hazard and show how they differ from threats. To conclude, I use literature to present examples of threats and solutions that actors have devised.

3.1.1 A definition of threats

Formal definition Threats are absent from the [Dunster \(2011\)](#)’s *dictionary of NRM* and according to the *Oxford English Dictionary*, threats have several definitions. The definitions that best fit the [NRM](#) context are: “A person or thing likely to cause damage or danger” and “the possibility of trouble, danger, or ruin” ([OED, 2015](#)).

I propose to define threats in the context of a [SES](#) as a 5-tuple $\langle \mathcal{A}, \mathcal{C}, I, D, E \rangle$ made of three main parts. Firstly, \mathcal{A} is a group of actors (that may be self-constituted) which are concerned about some characteristics \mathcal{C} of some goods or resources (subsequently called *asset*) that they possess, or use. Secondly, I contains a set of infrastructures in the sense of [Anderies and Janssen \(2013\)](#), that is inclusive of human, both soft (*e.g.* rules) or hard (*e.g.* canals) and natural (*e.g.* forest) or human-made (*e.g.* forest cuts) types. Infrastructure is here used in a broad sense that can be understood as constraints or at least elements that could influence characteristics of assets \mathcal{C} . Last, D and E contain events, both human decisions (in D) or environmental dynamics (in E), that may affect directly or indirectly, through I , the asset. [Figure 3.1](#) proposes a vision to unify and [Table 3.1](#) summarizes the elements of the 5-tuple.

Let me illustrate this definition with a classic [CPR](#) threat: exhaustion. Bob and his fellow fishermen constitute the group of actors \mathcal{A} that use the (common) fish resource, which abundance, \mathcal{C} , can face the threat of exhaustion. Infrastructure I is made of a rule on the size of nets and legal fishing areas (soft) or of the storage capacity in the local market (hard). Human decisions D

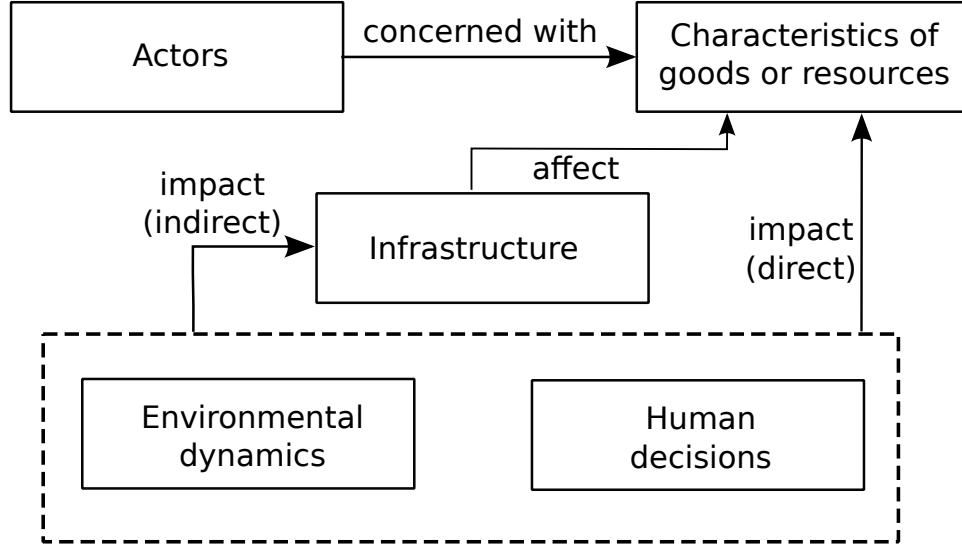


Figure 3.1: Relations between elements constituting threats.

Table 3.1: Elements characterizing a threat.

Id	Component	Definition	Examples
\mathcal{A}	Actors	A group of people, the target, that are or could be affected by the threat through goods	All dwellers, fishermen, managers of a natural park
\mathcal{C}	Asset characteristics	Characteristics of goods or resources that can be touched by the threat	Fish stock, biodiversity
I	Infrastructure	Natural, human-made or human elements that impact \mathcal{C}	Forest, forest cuts, dams, hunting season
D	Human decisions	Actions of people that impact \mathcal{C} or I	Fish extraction, litter
E	Environmental dynamics	Actions of nature that impact \mathcal{C} or I	Floods, tornados, invasive species

can include quantities of fish taken or periods to go fishing and environmental dynamics E invasion by a noxious species.

Precisions on \mathcal{A} Actors of \mathcal{A} form a group that can be self-constituted, or delimited by an analyst, and that does not necessarily include all whom could be affected by the threat or all whom could have an impact on it. Actions in \mathcal{D} include decisions that are made by people who do not necessarily belong to \mathcal{A} .

Consider a watershed containing two villages located along a river. In both villages, farmers pump water out to irrigate their fields. Water is often scarce and thus farmers from the upstream village tend to pump as much as they can to favor their crops. If we consider water scarcity as a threat, downstream actors can be a self-constituted target \mathcal{A} trying to defend their access to water (\mathcal{C}). In this case, \mathcal{I} pumping facilities and irrigation systems. \mathcal{E} includes rain and water flows from the river and \mathcal{D} includes pumping decisions from upstream and downstream actors. Boundaries are difficult to delineate. One could include climate change in \mathcal{E} , or the village water system in \mathcal{I} .

In a second example, let us suppose that a factory and some farmers pump out of the same aquifer that usually fills up every year. Farmers have noticed that water is getting difficult to obtain since the factory has been established: the factory possesses deeper drills and uses significant quantities of water. All actors (farmers and factory) are interested in water and could be part of the target since they would all be affected by an increase in water scarcity. Farmers could also be the target themselves, trying to limit the factory's water consumption. The choice of the set of actors is open, and several options can be advocated for.

3.1.2 Risk, uncertainty et al.

Risk, uncertainty, hazard, vulnerability are terms that have already been used in [NRM](#) with a meaning close to threats. In order to understand the concept of threat and its usefulness, I need to explore those concepts to clearly state how they differ. I first provide definitions of these concepts in [NRM](#) context and then relate them to threats. Three main axes are to be considered: describing, evaluating consequences, and solving issues (threats).

The description phase contains hazards and hazard rating. Threats used as a definition belong to this category. The *dictionary of NRM* ([Dunster, 2011](#)) defines *hazard* as “any action or substance that has a potential to create an adverse effect without reference to the probability of the potential actually occurring” and “the condition of stands, trees, and the prevailing environmental conditions, which are conducive to the creation of the hazard”. According to the first definition, an alien invasion, a nuclear power plant explosion or the apocalypse are hazards, as is a tsunami ([Bryant, 2014](#)). With this definition, events with less extreme consequences than the previously cited ones such as

a storm, or rain at the wrong time are considered hazards. The second part of the definition is interesting since it considers that elements which lead to the increase in the probability of a negative event potential are also called hazards. These elements can be natural (drought increasing probability of fires (Meyn et al., 2010)), or human-induced (changes in population density and continuity patches affecting probability of fires (Archibald et al., 2012)). The identification of a hazard is often paired with *hazard rating* (Hernán (2010) even points out hazards of hazard rating) which is “a system of identifying and ranking individual stands in terms of the vulnerability to becoming conducive for the creation of the hazard condition” (Dunster, 2011).

Hazards are specific types of threats. They are threats that focus on environmental dynamics E and infrastructure I . There may be an underlying group of actors \mathcal{A} that could be targeted by the threat and the hazard is linked to some asset characteristics \mathcal{C} . Human decisions D are connected to the production of elements leading to the increase of hazard consequences, but do not include more general issues regarding NRM such as exhaustion or over-harvest linked to social dilemmas.

On the evaluation side, there is the notion of *risk* which is connected to hazards. In their white paper on risk governance, the Institute Risk Governance Council defines risks as “uncertain consequences of an event or an activity with respect to something that humans value” (Remm, 2005, p.19). Many other definitions exist and Aven et al. (2011) provide an overview of these. This definition is close to the definition given in decision theory. Taking advantage of this direction, I add the concept of *uncertainty*: “in decisions under risk, the decision maker knows the probability of the possible outcomes, whereas in decisions under ignorance the probabilities are either unknown or non-existent. Uncertainty is either used as a synonym for ignorance, or as a broader term referring to both risk and ignorance” (Peterson, 2009, pp.5-6). In NRM , it is said that risk analysis includes ways to objectively define probabilities, while uncertainties need probabilities to be subjectively constructed (Dunster, 2011).

Vulnerability is a concept part of the evaluation phase. According to the Intergovernmental Panel on Climate Change, vulnerability is “the degree to which a system is susceptible to or unable to cope with adverse effects of climate change, including climate variability and extremes. Vulnerability is a function of the character, magnitude, and rate of climate variation to which a system is exposed, its sensitivity, and its adaptive capacity” (McCarthy et al., 2001, p.995). Changes can be hazards, even though changes need not be negative, and evaluation of vulnerability to these hazards are a way to infer on capacity of people to cope with these changes. These concepts are linked to tackling or absorbing threats rather than identifying and defining them clearly.

Finally, describing and evaluating consequences lead to devising ways to limit or solve threats. For instance, *hazard reduction* gathers ways to limit hazards consequences.

The notion of threat is part of the description phase since it neither contains evaluation methods nor asks for solutions. Threats as described here are considered a diagnosis.

3.1.3 Design principles seen as answers to threats

[NRM](#) can be framed as an instance of social dilemma. Initial attempts to understand it using game theoretical principles [Hardin \(1968\)](#) resulted in a dead-end. The research of Ostrom and colleagues has revealed 8 necessary design principles to sustainable [CPR](#) management (Table 2.4). These principles can be seen as answers to threats. If one looks at these principles thinking “suppose that this principle is not respected then ...”, a threat appears (mainly mismanagement of the resource resulting in unsustainable use, *i.e.* exhaustion in the long run, or pollution).

For instance, one of the principles is that monitors who actively audit biophysical conditions and user behavior are at least partially accountable to the users and/or are the users themselves ([Anderies and Janssen, 2013](#)). If such monitoring is not respected, then threats such as corruption and decay (exhaustion or pollution) of the resource emerge. Clearly defined boundaries are a principle according to which the boundaries of the resource system and the individuals or households with rights to harvest resource units are clearly defined ([Anderies and Janssen, 2013](#)). If boundaries are not well defined, then threats such as decay and misuse can arise, such as what is currently happening in some fisheries in Africa ([Standing, 2008](#)). Table 3.2 lists all of these principles and relates them to threats that could occur if they are not respected.

Thus, it is possible to see all design principles through the lens of threats. A clear identification of threats may help to understand rule-making and constraints that actors impose to their use of resources.

3.1.4 Some examples and solutions

In this section, I give a few well documented examples that exist in the [CPR](#) literature emphasizing the notion of threat. I give two examples of how actors managed to cope with threats of overuse and exhaustion in [CPR](#) contexts. Then, I give an example of threats to public water. Table 3.3 contains a framing of those examples using the threats semantic.

Rice farming in Bali, Indonesia [Lansing \(2009\)](#) describes the case of Balinese farmers making regular offerings to water temple gods to trigger the rice seeding period (Figure 3.2). For centuries, farmers had adopted a cultivation pattern with two annual rice crops. During the so-called green revolution of the 1960s (see [Griffin et al. \(1974\)](#) or [Evenson and Gollin \(2003\)](#) for critical assessments), a program was launched backed by foreign (Dutch) engineers

Table 3.2: Ostrom’s CPR design principles (Table 2.4) under the lense of threats. The table is intended to be read as: “if design principle x is not guaranteed, then a threat linked to elements of I or D could impact characteristics of assets \mathcal{C} , which would be a concern for a group of actors \mathcal{A} .”

Design principle	I	D
Clearly defined boundaries - actors		Entry (extraction) external actors, free-riding
Clearly defined boundaries - resource		
Congruence between appropriation and provision rules and local conditions - restrictions	Size of nets	Overharvesting, unsustainable harvesting
Congruence between appropriation and provision rules and local conditions - benefits		Underinvestment in labor
Collective-choice arrangements	Unappropriated rules and buildings	Non respect of rule
Monitoring - presence		Free-riding
Monitoring - accountability		Corruption
Graduated sanctions	Too drastic sanctions or no sanction	Non respect of rule, unwillingness to participate
Conflict-resolution mechanisms		No cooperation
Minimal recognition of rights to organize	Absence of local organization	Non legitimacy of organizers
Nested enterprises	Bad scaling of infrastructure at inappropriate levels	

Table 3.3: Examples taken from the literature described using threats defined as $\langle \mathcal{A}, \mathcal{C}, I, \mathcal{D}, \mathcal{E} \rangle$.

Example	Threat	\mathcal{A}	\mathcal{C}	I	D	E
Rice, Bali	Pest	Farmers	Rice harvest	Fields, irrigation scheme	Cropping period	Pest
Lobsters, Maine	Exhaustion	Fishers	Lobsters abundance	Lobster biology	Catch	Reproduction rates
Lakes, Bangalore	Ban- Pollution	City dwellers	Water quality	Water treatment facilities	Involvement of actors & government	Water flow

and imposed by the Ministry of Agriculture: farmers had to grow a specific type of fast growing rice that enabled up to three crops per year, with the help of chemical inputs. While this strategy allowed an increase in production in following years, pests adapted and wreaked havoc on crops, since rice was available in random patches all year long. New rice types were created and pests adapted over again. A red queen's race was engaged.

Lansing identified that water temple ritual roles went much further than simple religious functions. They allowed farmers to both manage, in a very efficient manner, water distribution while limiting the impact of pests on their rice fields. Since there was a synchronization in crops that had to be done after collective visits to the water temple, there were periods of very low food availability for pests, controlling their population.

In this case, the threat is the loss of crops due to pests, the actors group is all farmers and the characteristics of the goods are rice harvest quantities. Environmental dynamics contains knowledge of pest and rice growing rates. Infrastructure could be rice fields, and up to a certain point, there is a need for including irrigation systems. Decisions contain cropping dates. As shown by Lansing, a way to deal with this threat was to create and follow a rather mystical procedure which was soon reinstated.

Lobster farming in Maine, USA Another classical example of appropriators dealing with the threat of exhaustion or overharvesting is the example of Maine lobster fisheries ([Acheson, 1975, 2003](#)). Fishermen devised the rule of marking the tails of lobsters bearing eggs with a V-notch (Figure 3.2). It is forbidden to keep and sell such a trapped lobster. All fishermen and buyers know the rule. It is also forbidden to keep and sell lobsters below a certain size.

This case shows how to deal with the threat of low reproduction rates and differentiation of resource units by creating a rule to easily spot offenders



Figure 3.2: A traditional water temple procession in Bali and a V-notched female lobster in Maine (Pictures are from Wikipedia, respectively Ken Eckert and National Oceanic and Atmospheric Administration (NOAA) under a Creative Commons Attribution 3.0 license).

so that cheating is limited. The actors are the fishermen and the resource (the good) characteristic that is under threat is the lobster stock. There is no specific infrastructure and the environmental dynamics is mostly linked to reproduction patterns (*i.e.* lobster biology). Decisions are linked to the type of lobster to catch.

Water quality in urban lakes, Bangalore, India Due to increasing urban pressure, lakes in Bangalore are more and more polluted (Nagendra and Ostrom, 2014). This pollution is a threat to all inhabitants, and even more to those directly dependent on water quality (the characteristic of water under threat). In the study, the authors show that collective action can be successful for the management of what they call an urban lake commons, a commons that fits the definition of a public good. In some cases, those involved in the management succeed to improve water quality and fail in other cases. Whatever the result, these lakes face the same threat where the environmental dynamics are linked to limited water flows. The infrastructure is the (poor) water treatment management and decisions are the involvement of citizens and their capacity to create ties with the local government.

3.1.5 Conclusion on threat definition

In this section, I made the point that threats are an essential part of the study of NRM. They lie at the core of the need for such a management, as shown with the example of the well-studied CPRs. To define a threat, one has to look for five main elements: a set of actors \mathcal{A} in relation with assets characteristics \mathcal{C} that could be affected by the threat, the infrastructure I and the environmental dynamics E , as well as actors decisions D that could have an effect on \mathcal{C} . While

threats are connected to other concepts, such as hazards, risks, uncertainty, or vulnerability, threats capture as many aspects as possible: natural elements, human infrastructure and decision making. These elements can be the base for information seeking, or sharing (Chapter 4). This definition of threats allows a complex view that can include actors' individual rationality (decision) in relation with their environment, be it man-made or natural.

This definition has the potential to be used to describe collective situations, as in this dissertation, that could go wrong or to assess clearly a fact that can be mitigated through rules, or norms, or knowledge.

Characterizing a threat is not enough. A natural question that comes after is: what to do? The definition does not suffice to answer that question since it can include too many different types of threats that call for specific treatments. There is a need for further clarification. In upstream downstream situations, in a natural park and in a collection of fields irrigated with the same reservoir, threats are different in essence. In the following section, I propose a typology that will enable identifying different types of threats and strategies to tackle them. Some of the strategies include information seeking and sharing, as illustrated by the cases investigated in this thesis (Chapters 9 to 11).

3.2 Typology of threats

Identifying threats is a useful lens through which we can understand the decision-making processes, be it at the individual level, such as changing practices, or at the collective one, such as crafting rules. To demonstrate how effective this concept is, I introduce key characteristics that threats can verify, leaning towards a typology that I propose subsequently. Determining these properties is suitable to better understand the type of answer users implement, *i.e.* their strategy, to tackle and/or limit the negative effects of threats. I investigate two key properties: internality and excludability.

3.2.1 Properties

For now, the concept of threats has been defined and characterized. It enables a precise identification of underlying elements prompting the necessity of devising rules or institutions. CPRs and related issues have been identified, bounded, explored and separated from other types of resources thanks to Ostrom's goods typology (Section 2.1.1). The concept of threats needs a proper typology to enable an accurate diagnosis and adapted tackling strategies. In order to characterize threats, I provide two properties below that will enable the identification of different types of threats: internality, a characteristic of the threat and excludability, a characteristic of ways to tackle the threat.

3.2.1.1 Internal threats

The first property that I consider is a characteristic that I call *internality*. It is related to questions such as: are D decisions of actors of \mathcal{A} ? Are people outside of \mathcal{A} concerned with the threat? Do actors that do not belong to \mathcal{A} at the origin of the threat?

A threat is *totally internal* if infrastructure I belong to actors of \mathcal{A} , if the decisions D are made by actors of \mathcal{A} and if only those actors are concerned with the environmental dynamics E. This property depends on the choice of \mathcal{A} . In most cases, there are several ways to draw the boundaries of \mathcal{A} . The totally internal case is the basic case studied in the literature on the commons, where issues are common and linked to actors only. On the opposite extreme, if the threat is linked to infrastructure that does not belong to the actors (a failing water treatment plant), to decisions of actors outside of \mathcal{A} or to environmental dynamics that affect actors who do not belong to \mathcal{A} , then the threat is *non internal*. Thus, there are three dimensions in the internality concept. The more the infrastructure or the decisions are outside the reach of actors of \mathcal{A} , the more environmental dynamics touch other actors, the less internal the threat is.

Totally internal threats have the most demanding conditions and represent the traditional tragedy of the commons for instance, when isolated from links to the rest of the economy (exhaustion of a water resource has consequences to users that do not seem initially related to the resource). A non internal threat, as experienced by Bob and his fellow fishermen, could be foreign boats looting the fish stock. An internal threat would be insider overharvesting. The upstream downstream scenario could be seen as an example of non internal threat for downstream actors in the sense that consequences are limited to the target and the origin of the threat is from upstream.

A possible solution to internalize threats is to change the system boundaries, thus making non internal threats internal and traditional theory applicable. However, some systems including the ones studied in this thesis are structurally open. One could internalize all issues by creating a system that would include all inhabitants of the planet (even though we would still depend on the Sun or climate), but the explicative power of this vision would probably be rather limited. In a less extreme manner, one could decide to extend the physical boundaries of the system, or to include more actors, but it does not provide an actual tangible way to tackle threats.

Some threats are intrinsically non internal, especially when relative to a set of actors. If the fish stock that Bob subtracts units from is overharvested because of the intrusion of foreign boats, then the threat is non internal and should be considered non internal. For downstream actors, the upstream actors cannot simply be considered internal actors to solve a threat. Downstream actors have to find a way to change the system boundary so that upstream actors feel engaged to help solve the threat. Internalization of threats is a

strategy that requires work.

The qualification of “internal” certainly reminds the reader of the property of externality which is widely used in economics. An externality is a cost or benefit that affects a party who did not choose to incur that cost or benefit [Buchanan and Stubblebine \(1962\)](#). Air pollution due to car use is a negative externality to society, a pizzeria that sells more pizzas thanks to a bar located next door benefits from a positive externality. This concept is seen from the point of view of an actor or a group of actors creating something that others will have to deal with. In our case, we are in the position of a target that has to face a threat. Thus, it seems natural to define the concept of internality. Actors of \mathcal{A} can anticipate and communicate the externalities they produce as a strategy to reach non-internal threats (Chapter 10). A second property is necessary to complete the threat typology: excludability.

3.2.1.2 Excludable threats

The second element that the target needs to identify is the *excludable* characteristic, a property connected to solutions to tackle the threat. This property is interesting in the case of a target representing a group of actors, otherwise it is a case of non-collaborative game theory. The excludable property deals with questions such as: how collective solutions need to be? Can actors find and implement solutions by themselves?

The difficulty in social dilemmas lies in the impossibility for individuals to solve the dilemma by themselves. In the tragedy of the commons, a single individual who decides to play by the rules and limit his own herd size does not change the fate of the common. He is simply a “sucker” since all the others take advantage of what is left of the common pasture.

Solutions to threats can be collective, but they can also come from individual behavior, or somewhere in-between. A threat is said to be *totally excludable* if a single individual of the target can tackle the threat by an individual action. It is *non excludable* if the solution involves a collective answer to the threat. If a threat is totally excludable, then each one can mitigate the threat by personally adopting a proper strategy, when possible. If the threat is non excludable, then individual actions have little effect on the threat.

In most cases, there is no single way to tackle threats, some solutions can be individual, others collective. Suppose Bob wants to limit overharvesting. He can decide by himself to use nets with holes big enough to let small fishes pass. If he is alone to make this decision while other fishermen decide to continue to overfish, it will not be enough. This threat is thus non excludable. Since it is quite difficult to privatize moving wild fish, sustainable solutions need to be devised collectively. As other fishermen, Bob uses a collective refrigerated room to store his fish. The refrigerated room is organized as a club good, a solution to the threat of losing one’s catch. Private solutions could have been imagined as well by using individual refrigerated rooms. But the collective

Table 3.4: A typology of threats

		<i>Internality</i>	
		<i>Low</i>	<i>High</i>
<i>Excludability</i>	<i>Low</i>	Public	Common
	<i>High</i>	X	Private

solution was found to be cheaper.

Solutions devised by actors to face threats can range over the excludability dimension. In some cases, for instance in usual CPR issues, solutions are intrinsically non excludable. Actually, excludable threats may be considered irrelevant at first sight. However, from information sharing perspectives, this type of threat is particularly relevant since it points out issues such as limited experience or knowledge, or ill-known environmental dynamics. The mere existence of the threat may be unknown.

In the end, and as I will demonstrate in the rest of the thesis, the internal and excludable properties allow to apprehend the type of threat faced by actors using some good or resource.

3.2.2 Typology

Four types of threats can be defined by combining the internal and excludable properties. The names are inspired by goods types since the categories fit well, which makes remembering them easier. These threats are summed up in Table 3.4.

I qualify a low excludable and low internal threat as public. This kind of threat includes threats such as floods or foreign fishing boats.

I call a low excludable and highly internal threat as a common one. These threats include social dilemmas and associated free-riding or overuse and internal pollutions.

Finally, a highly excludable and highly internal threat is private. Such threats are more related to the lack of personal or collective knowledge. These threats will be particularly interesting to deal with when we focus on these issues from the perspective of information sharing.

A highly excludable and internal threat is here left as a hole that could be filled with an appropriate case. In this thesis, the cases did not demonstrate this type of threat, therefore I did not investigate it any further.

In the rest of the thesis I will investigate information sharing stakes for users facing those different kinds of threats, except for the last one.

3.2.3 Goods and threats

Goods are separate from threats. Table 3.5 shows examples of goods that face different kind of threats. Various characteristics of goods of all types may be touched by threats of all sorts. Initial studies in the commons literature are oriented towards a group of actors that share a common good facing common threats such as overuse, depletion or pollution. The typology of threats introduced here enables to identify and think of threats that are less obvious, or that do not belong to the commons category.

Bob owns a boat. His fellow fishermen do as well. Boats are both subtractable and excludable. Thus, they are private goods. All types of threats can happen to individual boats or to a set of boats. Hurricanes, a non-internal (since it touches other people than the fishermen) and difficult to exclude (the investment is probably high) threat, thus a public threat, can happen and destroy the shore and the boats. Boats can also incur issues due to poor maintenance (a private threat).

Goods and threat types are independent. There are types that can be thought of as associated (CPR and common threat), but all different combinations exist. Adding the threat dimension to goods or resources used or possessed by actors allows to widen the view that one associates with the said good or resource, since the threats, issues, or concerns that can arise are of different types. As will be shown in the rest of the thesis, identifying the threat type enables to turn to specific strategies. For instance, public threats require the involvement of actors that are not in the threat, common threats need internal cooperation, and private threats are mostly linked to lack of knowledge and thus favor information sharing (Section 4.5).

3.3 Adding threats to the SES framework

In this section, I advocate for a clearer mention of the threats that actors face in the SES framework. I first show that there is no specific mention of threats in this framework and motivate the addition of threats, then compare the robustness framework dedicated to identifying vulnerabilities (Anderies et al., 2004). I explain why threats provide another vision than this framework. Finally, I propose some variables to be explicitly added to the SES.

3.3.1 No threats in the SES framework

Vogt et al. (2015) propose to add variables to describe the ecological side of a SES. According to them, this part is not developed enough. As explained in Section 3.1.2, threats are part of a diagnosis. Threats force actors to make decisions to limit potential effects of its realization and is therefore a fundamental part of (collective) decision-making. I claim that threats need to be added to the SES framework.

Table 3.5: Threat examples for each type of good (Table 2.1). Oyster farming examples are reformulation of threats found in the case studies (Part III).

[†] OF stands for oyster farmers.

Asset	Threat type	Asset	Threat	\mathcal{A}	\mathcal{C}	Example I	D	E
Public	Public	Water	Microbiological bloom	OF [†]	Water quality	Sewage treatment plants, rules on individual water treatment	Improvements in water treatment	Water flows
	Common	Image	Undermining reputation	OF	Image	Depuration basins, harvest class	Sell not purified oysters	Microbiological blooms
	Private	Water	Faulty toilets	OF	Water quality	Connection to sewerage network	Investing in connection	Water flows
Common	Public	Fish stock	Foreign fishing boats	Fisher	Fish abundance	Unclear boundaries, industrial-size boats	Extraction	
	Common	Fish stock	Exhaustion	Fisher	Fish abundance	Fishing technologies	Fish caught	Reproduction rates
	Private	Fish stock	Access to fish	Fisher	Fish location	Fishing periods	Choose fishing area	Fish move
Club	Public	Lease area	Access to lease area	OF	Tables, Access rules	Trespassing by non authorized users	Exclusive access	
	Common	Docks	Docks degradation	OF	Docks condition	Docks	Collective work, docks maintenance	Extreme weather
	Private	?	?	?	?	?		
Private	Public	Oysters	Harmful algal blooms	OF	Oysters health	Catchment area	Upstream farmers fertilizers input	Water flows
	Common	Oysters	Herpes virus	OF	Oysters health		Unclear role of practices	Virus dynamics
	Private	Oysters	Sea bream	OF	Oysters health	Tables, nets	Ally with fishermen	Sea bream dynamics

Filling in all the required information of the [SES](#) framework is already a long and arduous task for an analyst. The addition of threats makes the task even larger. A [SES](#) is a partial vision of a system, with an entry chosen by the analyst who selects a subset of actors, a specific resource system and a set of rules, some indicators, and specific interactions. By choosing those, the analyst has to set aside other types of interactions which may have consequences on the [SES](#) (in real life, actors may interact on many different action arenas and processes considered external may have important effects on the [SES](#)), projecting very complex and often hard to predict situations on a framework composed of a set of variables, loosing information at the same time in the hopes of providing the quintessential elements.

When assuming that a system is complex, one has to reject the reductionist idea according to which understanding subsystems perfectly enables a finer understanding of the superior level ([Sapolsky and Balt, 1996](#)). When describing social or ecological processes, one could look ever closer, probably without being able to derive useful knowledge at the [SES](#) level. Even though interesting and related, it may be irrelevant to go very deep into the study of how tree leaves grow when trying to understand how people manage a common forest. Once again, it is a question of choice. These choices are necessary, and analysts should keep this in mind, especially when presenting results. Despite this limit, which is intrinsic to the study of complex systems, where the whole is not the linear sum of its parts, I believe that adding threats is fundamental.

In “a diagnosis approach for going beyond panaceas”, [Ostrom \(2007a\)](#) introduces the [SES](#) framework. The paper title gives the general idea behind the framework. However, in the [SES](#), there is no apparent mention of free-riding, natural risks, internal pollution patterns, overuse, or other types of threats that actors of the studied [SES](#) have to face. As advocated in this chapter, threats are elements that need to be considered while making a diagnosis of a situation. Even more, they can be considered at the origin of rules or infrastructure as discussed in Section 3.1.3. There are not simply closer studies of subsystems. The immediate step after making a diagnosis of a situation is to think about consequences and thus make decisions. Threats are part of decisions that need to be made by actors and cannot be left out of a diagnosis.

Of course, at the origin of the field are common threats that lie at the very core of [NRM](#). Hardin’s paper and subsequent research by other scholars of the field exist because of the existence of threats, otherwise, there would be little to talk about. Threats are present in the [SES](#) framework but not explicitly. For instance, the need for (I9-I10¹) monitoring and evaluative activities is due to possible threats to the RS or RU. Conflict (I4), a threat explicitly mentioned, may arise. The only other threat that has a variable devoted to it is “Pollution patterns” (ECO2), in the category “Related ecosystems”.

Given their position at the core of the field, I claim that threats should be

¹The codes are those of the [SES](#) framework (Table [B.1](#), p.260).

added explicitly to the [SES](#) framework which is supposed to enable a diagnosis of a situation, where some actors interact with a renewable natural resource. Before proposing a practical addition of these threats to the framework, we need to explore a related framework: the robustness framework.

3.3.2 Threats in the robustness framework

The robustness framework ([Anderies et al., 2004](#), p.1) is a framework that is intended to “identify potential vulnerabilities of [SESs](#) to disturbances”. The authors identify four main nodes: resource users (the actors of the [SES](#)), resource (that encompasses RS and RU), public infrastructure and public infrastructure providers. These nodes are linked through some dynamics. All nodes and links can fail, internally or externally, due for instance to actors’ internal conflicts (decisions) or to environmental dynamics.

[Anderies \(2006\)](#) uses the robustness framework to describe systemic changes for a lost civilization, the Hohokam of the Phoenix Basin. By unfolding boxes such as resources and public infrastructure, civilizational choices are analyzed, balancing efficiency and vulnerability: an increase in irrigation efficiency came with an increased vulnerability to drought, possibly leading to the fall of the Hohokam civilization.

In the context of a [SES](#), the robustness framework opens ways for actors to think about potential “vulnerabilities” that can be identified to threats and described using the threat formalism. Recognizing these vulnerabilities enables actors to diagnosis their own weakness(es). However, this framework comes with two limitations. Firstly, threats are merely identified. The framework does not propose ways to describe in a thorough manner those vulnerabilities while threats come with an appropriate formalism. Secondly, it does not provide effective strategies to tackle threats contrary to the typology considered in this chapter.

3.3.3 Adding threats

I propose to add new variables to the [SES](#) framework that would focus on threats and force analysts to think of and describe precisely elements related to this threat, or even point out lack of knowledge (Chapter 4).

I list in Table 3.6 new variables to be added to the [SES](#) framework, sometimes replacing existing variables using a more encompassing one. For instance, I suggest to replace (ECO2) “Pollution patterns” by (ECO2) “Public threats”, with pollution patterns as a third-tier variable. All types of goods are not considered in the [SES](#). In the same spirit, I do not list directly the different types of threats in the framework. I have shaped threats to suit the precise descriptions of [SESs](#) that are provided in the framework.

Table 3.6: New variables to be added to the SES. Variables codes that already exist in the framework, emphasized in italic, are intended to replace those that are defined in the original SES framework.

Code	Variable
RS10	Threats to resource system
	RS10a - Threats due to unclarity of system boundaries (ecological openness, contiguity with other systems)
	RS10b - Threats linked to facilities (ecological consequences, free-riding)
	RS10c - Threats to resource system (fires, droughts)
RU8	Threats to resource units
	RU8a - Biological threats (virus, pest)
	RU8b - Human-related threats (theft, overharvesting)
<i>I₄</i>	Threats to collaboration (conflicts, free-riding possibilities)
<i>ECO2</i>	Public threats
	ECO2a - Pollution patterns
	ECO2b - Facilities

3.4 Conclusion

Threats are an essential factor to understand decision-making and information-seeking in the context of [NRM](#). The existence of [SEs](#) is linked to the existence of a renewable resource that actors want to exploit, and the existence of institutions is linked to the existence of threats. Threats prompt and force interactions between users of a resource. I proposed a definition of threat, relative to characteristics of assets \mathcal{C} shared by actors \mathcal{A} , that may be affected by existing infrastructure I or human decisions D or environmental dynamics E . I also proposed to characterize threats using two main properties: internality and excludability. A threat is internal when the threat depends on decisions of the designed actors and originates from their infrastructure. A threat is excludable when it is possible for a single actor to choose a strategy that would prevent the threat from touching the actor. These two properties enable to identify three types of threats: public threats (non-internal and non-excludable), common threats (internal and non-excludable) and private (internal and excludable). Finally, I have advocated for the addition of threats as part of diagnoses of [SEs](#) with the intention of helping individual or collective decision-making and information-seeking.

Threats have been addressed through numerous means, that include all forms of institutions, rules, infrastructures - sometimes missing the goal, sometimes ensuring long term sustainability of the resource. In this thesis, I investigate particularly the implementation of a specific type of infrastructure that

may impact threats: information sharing artifacts. I will explore this element in the following chapter.

Chapter 4

Information Sharing for Natural Resources Management

Si j'aurais su, j'aurais pas venu.

La guerre des boutons

Louis Pergaud, 1912

Information has already been studied as a global good ([Hess and Ostrom, 2003](#)). Specific issues arise when information is shared in local settings. I explore this subject in this context by answering the following questions: What kind of information can be shared? How is it shared and what for?

Actors facing a threat may develop information sharing artifacts as a possible infrastructure to cope with it. This explains the focal point of this thesis. These artifacts are a possible solution to deal with threats, part of a broader set of information sharing solutions, which are a means among many others to cope with threats. I propose a characterization of these artifacts that allow for comparison with other types of artifacts in different situations. Then, I state the stakes for information sharing for each type of threat that has been defined in the previous chapter (Section 3.2). Finally, I interpret some results that have already been investigated in the literature on information sharing to manage common resources.

4.1 More information on information

Up to now, I used the word information without precisely defining the meaning of the concept in this context. In this section, I dive into fundamentally diverse views of information by studying the process of information creation, transmission and reception. I show that depending on why one studies information, one may use various definitions and perspectives on this multidimensional object. Then, I give and motivate the definition that I will use in the context

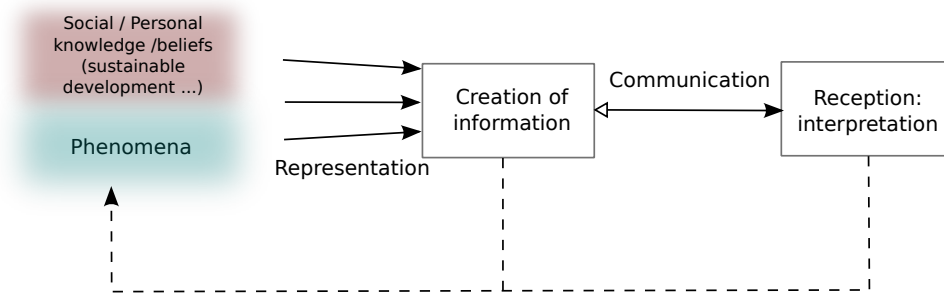


Figure 4.1: Different steps for information. These steps are potential steps that do not necessarily occur.

of the thesis: “information is a difference that creates a difference” (Bateson, 1972). Finally, I give an interpretation of information as a good made non-subtractable by modern information and communication technologies subject to issues such as openness and accessibility.

4.1.1 Information in various contexts

Information is fundamentally ubiquitous in its nature. Figure 4.1 captures those different moments where information has a different role or poses various problems. Several steps have to be distinguished.

Creation First, information has to be created. Information is a representation of perceived phenomena into some kind of language that depends on social and personal knowledge and beliefs, *e.g.* numbers if it can be measured, words or concepts. Creation of information may be a difficult step. For instance, this thesis is the result of this process. It emerged by interpreting a large set of such phenomena added to a set of social and personal knowledge and beliefs. In the thesis, I will suppose that this information is translated in a language that can be transmitted. In an ecological approach of information, some authors, such as Gibson (1978), consider that the phenomenon itself contains signs that do not need to be translated it into a language. This type of directly interpretable signs are particularly important for actors dealing with an uncertain environment, which is the case in SESs.

Bob knows that the presence of a specific type of clouds in the sky indicates the imminence of a storm. In this case, there is no need to translate the information into a language. However, he can formalize the information as “a storm is coming”, and then communicate it with others.

Storage Once the information is created or collected, it is stored somewhere: in someone’s mind as a mental or internal representation, or in a more tangible

artifact as an external representation (text, recording, formula...). Internal and external representations are actually in interaction, enriching each other, in a dialogue, especially for those who create the external representation (Kirsh, 2010). This thesis is the result of such a dialogue. Kirsh (2010) discusses how external representations, typically through some artifact, can help thinking. Among the advantages of these representations are their potency to “change the cost structure of an inferential landscape” or “serve as a shareable object of thought”. These elements are discussed in the rest of the thesis starting with Section 4.2 that tackles challenges for artifacts.

Communication One of the characteristics of a representation of information is that it can be transmitted. The question of proper transmission covers two distinct elements: quality of signal and interpretation by the receptor. The first element can be seen under a technical lense. Shannon and Weaver (1959) created a theory of information where they studied how information could be sent from an emitter to a receptor without altering the signal. The emitter needs to be sure that the message is perfectly transmitted. The scope of this thesis goes beyond the mere question of proper transmission.

The other side of transmission quality is the question of interpretation, *i.e.* of meaning. This element is equivalent to a communication situation. Suppose two people are conversing, the first person gives an information that she formulated in her own words. This information is a projection of phenomena, filtered by this person through knowledge and beliefs and expressed in words that have specific meanings for her. The other person receives this information and has to find a way to reverse the projection using her own understanding of the words used. In an oral conversation, there may be misunderstandings. Written information is subject to the same types of difficulties especially since the author is usually not present to detail the meaning of the stored information. Since information can be exchanged, Figure 4.1 features a white arrow from the receptor back to the creator.

Information may then have an impact on the creator and the receptor, and may feed back into the phenomena itself, as represented in Figure 4.1 using the dotted arrows.

A difference that makes a difference The simple process represented in Figure 4.1 shows that information can be thought of at diverse stages, under distinct shapes. This variety should not be surprising since information is everywhere and poses an immense range of questions. Information has been studied under different perspectives in various fields. Table 4.1 gives some acceptations of information in a selection of disciplines and gives an idea about how loose this concept is. Information is a key element that affects the minds of individuals and can be interpreted in different ways depending on the person’s knowledge and beliefs (psychology). Information impacts relations that

Table 4.1: Definitions of information (Adapted from [Maurel, 2012](#), p.251).

Field	Vision of information
Ordinary sense	Abstract mass-noun used to denote any amount of data, code or text that is stored, sent, received or manipulated in any medium (Adriaans, 2013)
Information science	Elements written on some kind of artifact to transmit knowledge (for instance, on paper or on a computer file)
Information theory	Reproducing at one point either exactly or approximately a message selected at another point (Shannon cited in Mackay, 2003 , p.3)
Knowledge management	“Descriptions, answers to questions that begin with such words as who, what, [where,] when and how many. Information systems generate, store, retrieve and process data. Information is inferred from data.” (Rowley, 2007 , p.166)
Computer science	Piece of knowledge regarding a phenomenon that has a specific meaning in a given context. In the context of data treatment, information is a piece of data that has been interpreted (or reinterpreted). The framework that determines this interpretation is made of all the knowledge and experiences of the one who is interpreting the information
Psychology	Set of elementary data aiming at creating knowledge. According to Shannon’s information theory, the message must bring something new to the receptor to dub these data as information
Sociology	Set of forms, conditions and effects of massive, regular, continuous, repeated (and even permanent) diffusion for an <i>ad hoc</i> audience of pieces of information, of intellectual expression, of mental pressure and social therapy (among many definitions)
Journalism	Any event or fact broadcast by a press agency, a newspaper, a radio or television

exist between individuals (sociology, journalism, economics) or within organizations (knowledge management). It needs to be stored efficiently on artifacts (libraries, computer science) and be transmitted in a lossless manner (information theory).

“The lack of preciseness and the universal usefulness of the term ‘information’ go hand in hand” ([Adriaans, 2013](#)). This sentence is the first of the article

on the concept of information in Stanford *Plato dictionary of philosophy*. As exposed in this section, information has been studied and formalized in a wide variety of contexts. The definitions given in those context relate to specific angles to approach this concept. With this in mind, in this dissertation, I do not intend to provide a definitive answer on what is the right definition of information. I will more modestly adopt a definition that fits with the needs of this thesis.

In the case studies actors deal with a vast range of information types and of transmission methods. Thus, I decided to opt for a definition of information that is as inclusive as possible. The goal here is not to restrict the study on very specific types of information that could be shared, but rather to understand the needs and goals of information creation and communication in the context of *NRM*. Thus, in this thesis, I use the definition of information given by Bateson (cited in [Maurel, 2012](#), p.252): “information is a difference that creates a difference”. This definition is broad enough to encompass all different types of information actors may be willing to share. It gives a sense of goal to producing and sharing information. This definition also gives the opportunity to disqualify something that is disguised as information if it does not create a difference.

This difference is a topic that has a huge impact on our society thanks to the increasing use of information technologies. Thinking of information as a good may help in understanding some of these issues.

4.1.2 Information as a good

Information can be considered a good ([Hess and Ostrom, 2003](#)). Information is not substractable. One’s own use of information does not make it less usable for others. It is (often) costly to produce and now, with the wide spread of information technologies, it has a marginal cost of almost zero to transfer. Being non-substractable, information can be either a public good or a club good. Only the question of exclusion remains.

At this point, I need to define concepts that are widely used in knowledge management: data, information, knowledge and wisdom (DIKW). The following definition of information is not the one that I use in the thesis (see previous section). I give here the classical definitions [Ackoff \(1989\)](#) gave (cited in [Rowley, 2007](#), p.166), that are sufficient here. The interested reader can explore ([Rowley, 2007](#)) for a discussion on these definitions:

Data “Symbols that represent properties of objects, events and their environment. They are the products of observation. But are of no use until they are in a useable (*i.e.* relevant) form. The difference between data and information is functional, not structural.”

Information “Descriptions, answers to questions that begin with such words

as who, what, [where,] when and how many. Information systems generate, store, retrieve and process data. Information is inferred from data.”

Knowledge “What makes possible the transformation of information into instructions. Knowledge can be obtained either by transmission from another who has it, by instruction, or by extracting it from experience.”

Wisdom “Ability to increase effectiveness. Wisdom adds value, which requires the mental function that we call judgment. The ethical and aesthetic values that this implies are inherent to the actor and are unique and personal.”

Information technologies and technical issues are limited, for now, to data and information (in the sense of the definition). These two levels are those which are non-subtractable and easy to transfer. Knowledge and wisdom let appear much more individual-oriented elements, quite difficult to grasp and translate into transferable information. Because of this observation, if we allow ourselves to consider knowledge and wisdom as goods, they can be considered as private goods since they are subtractable and exclusive.

As a good, information has already been studied as a global public good (Hess and Ostrom, 2003). Information is often designed as a “commons” (in expressions such as Creative Commons) but it is a public good according to the goods typology (Section 2.1.1). Hess and Ostrom distinguish three key parts about information seen as a public good: the idea (knowledge, information, data), the artifact (book, computer file) and the facility (library, Internet). Figure 4.2 shows examples for each of the three parts. The authors insist on the paradigm change triggered by the movement of distributed information, mostly through the existence of networks such as the Internet. Beyond ideas, artifacts and facilities change rapidly with the emergence and spread of digital artifacts such as videos and enriched scientific articles, and facilities such as mobile phones or social networks.

In the case of the thesis, I am studying the implementation of information sharing artifacts as an infrastructure (*I*) to cope with threats. The context of the thesis is therefore the local one. Applying the concept of information as a public good to local settings is not a direct process. Several issues specific to information in local settings emerge. These issues are tackled in the following section.

4.2 Challenges of information sharing for NRM at local levels

In local contexts, information sharing raises specific issues and literature shows debated effects of information. Limited anonymity, strategic behavior, second

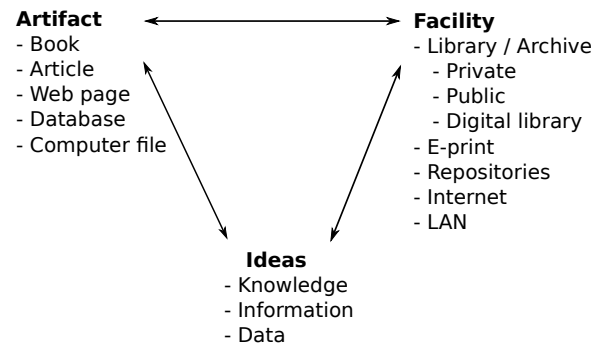


Figure 4.2: Forms of information [Hess and Ostrom \(2003\)](#)

order dilemma (free-riding on information) are issues that need different treatment than with more global information sharing systems. A linked question is to investigate the assumption according to which more information leads to cope more easily with threats actors face. In addition to new infrastructure building, information is already shared through other means, for instance social networks, which may limit the artifact impact. When evaluating the impact of information sharing system, a researcher needs to take into consideration the existence of other means for information to spread.

4.2.1 Intrinsic challenges for artifacts

Artifacts are specific types of external representations that have numerous advantages over internal representations, in terms of complexity or shared persistent referents, allowing to “think the previously unthinkable” ([Kirsh, 2010](#)) or converge towards a shared views on issues ([Adams et al., 2003](#)). With all these benefits, artifacts seem useful, if not necessary, tools for sustainable environmental management. I will not tackle this question in this section (see Part IV) but point out specific caveats developers of local information sharing artifacts need to pay attention to.

Limited anonymity In small-scale resource systems, anonymity is limited. Using an economic experimentation, [Villena and Zecchetto \(2010\)](#) have shown that subject-specific information can worsen the tragedy of the commons. Other experimental economics studies have shown that more information can on the contrary increase conditional cooperation by making known to all that norms, rules or laws are respected by others ([Chaudhuri and Paichayontvijit, 2006](#); [Janssen, 2013](#); [Janssen and Ostrom, 2014](#)). Thus, information has not *per se* a positive or negative effect, does not imply converging towards collective cooperation or defection. Context and granularity are important to understand the effects of information as much as they matter to understand field experiments results ([Castillo et al., 2011](#)).

Strategic behavior Secondly, disclosure of private information could entice strategic behavior both in writing inaccurate information or to get information about other's strategies. Using an econometric model based on a case study on commercial fishing in the Bering Sea, [Haynie et al. \(2009\)](#) have shown that information about bycatch avoidance led to conditional cooperation except when conditions tighten in which case, the information led to situation deterioration. Another side of information disclosure is trust in information. Because of the possibility of strategic behavior, when information comes from other actors, trust, between actors, and in information must be built and maintained, which can be a complex task ([Henry and Dietz, 2011](#)).

Free-riding Thirdly, free-riding can emerge from the existence of these systems since some actors can use information that have been written in an information sharing system without providing any information ([Evans and Weninger, 2013](#)). This type of free-riding can be considered a second-order dilemma since it occurs on an artifact which is supposed to provide a solution to free-riding regarding a resource. In global systems such as Wikipedia, we can wonder whether it is a real problem as long as the active community is big enough. In local systems, systematic participation of some and not others may deter those who share from keeping information sharing active, especially in the context of [CPR](#) since these actors could feel like they are suckers. In the context of public goods used by all actors, proactive ones may remain active (Chapter 8).

Information and sustainable management Fourthly in the context of [NRM](#), it is implicitly considered that the more the resource is monitored, the better it is known and thus managed. Some studies suggest that simple monitoring elements (such as green to signal that users can pump or red to signal they cannot) allow sustainable use of a resource, water under contamination threat in this case ([Li et al., 2014](#)). [Bell et al. \(2015\)](#), in a investigation on equity in Pakistan's irrigation system, show that information about water availability allowed a more limited use of water resources but did not lead to better water distribution. However, some studies argue that uncertainty around the state of the resource allow more sustainable management of the said resource. [Haynie et al. \(2009\)](#) illustrates this idea with a case of precipitated exhaustion due to precise information about a possible exhaustion to be. It is an example of self-fulfilling prophecy: the resource turned from a renewable one to a non-renewable one in actors minds. Thus, there is no direct link between precise information and sustainable and equitable management.

Conclusion These four challenges (limited anonymity, strategic behavior, free-riding and monitoring) are focused on possible limitations intrinsic to information sharing through artifacts. These limitations should not make us

oblivious that their impact may be hampered by the existence of other means to share information. Social networks are one of them. As much as understanding changes due to anthropic activities in the global climate requires a fine understanding of natural phenomena leading to change (Crowley, 2000), an understanding of other information sharing levers is necessary to analyze possible impacts of information sharing artifacts.

4.2.2 Without forgetting networks

Information and knowledge exchange (not necessarily linked to the environmental dynamics) are the basis for most interactions between users. They can be shared orally, without the help of any artifact. Spreading of information through networks, without artifacts has to be taken into account when trying to understand the impact of information sharing artifacts in a SES. It has been shown that (real) “social networks can be more important than the existence of formal institutions for effective enforcement and compliance with environmental regulations” (Bodin and Crona, 2009, p.366). An important part of the rich literature on social and economic networks focuses on effects of information transfer. Jackson et al. (2008) provide an overview of the field.

Investigating diffusion of information in real networks is lengthy and understanding consequences on decision-making can be difficult. It is necessary to know certain topological properties of the network to be able to understand and predict information diffusion (Bodin and Crona, 2009). In a thesis on social networks applied to marine protected areas management, Alexander (2015) investigated social relations between fishermen in Jamaica. To obtain a network that represents an actual real network, he had to determine different types of relationships between actors, then create questionnaires, organize focus groups and conduct semi-structured interviews with the goal of understanding these relations. In the end, the author obtained several social networks for these communities, allowing to derive understanding about how these networks create conditions for marine protected areas management. This process is very lengthy. In this thesis, I put a specific emphasis on the study of information sharing artifacts, but it neither implies that they are more important than social networks nor less important. More details are presented in the following section regarding information in the context of NRM.

4.3 Why, what and how?

Suppose fishermen are weary about a threat. Bob and the community of fishermen (actors of \mathcal{A}) have decided to build a new infrastructure in I : an information sharing artifact. Bob has been appointed responsible for this project which could make the threat evolve and be tackled more efficiently. Before creating any type of information sharing artifacts, Bob needs to define a goal for creat-

Table 4.2: Goals for information sharing using a threat perspective. Eventually, all these goals are useful for decision-making.

Threat	Goal for IS	Example study
Public	Legitimate action	Berkes and Jolly (2001)
	Common understanding of issues	Adams et al. (2003)
	Lobby	EMSTilligerry (2014)
Common	Dealing with conflicts	Rustagi et al. (2010)
	Conditional cooperation	Janssen (2013)
	Resource monitoring	Allen and Kilvington (2005)
	Avoid exhaustion, pollution	Nagendra and Ostrom (2014)
Private	Understand RS dynamics	Evans and Weninger (2013)
	Increase knowledge	Dalcanale et al. (2011)
	Change beliefs	Castillo Brievea (2013)
	Predict	Dalcanale et al. (2011)

ing such an artifact, then decide over the contents and information required to tackle this goal. Finally, he has to choose a facility to share this information.

I will use this perspective to present different facets of information sharing in a [NRM](#) context: why share information, what type of information can be shared and how and with whom to share this information?

4.3.1 Why share information in the context of natural resources management?

Information sharing can occur for a wide variety of purposes. I address some of them in this section. Since I adopted the idea that information is a difference that makes a difference, I claim that information sharing is eventually decision-making oriented. Numerous goals for information sharing can be found. The goals listed in this section are goals that I found in the literature. I present these goals as subgoals for tackling threats (Table 4.2).

In public threats, decisions in \mathcal{D} may contain practices and actions of actors outside of \mathcal{A} . Information sharing artifacts can be used to influence those actions in a manner that would suit actors of \mathcal{A} better. The shared information may lead to a common understanding of issues ([Adams et al., 2003](#)), be used to lobby ([EMSTilligerry, 2014](#)) or to legitimate action ([Paget et al., 2016](#)): internal representations may evolve and practices of \mathcal{D} could change.

To tackle private threats, actors of \mathcal{A} may share information to collect environmental information, elements of \mathcal{E} ; or actors decisions in \mathcal{D} . The goal is to understand the dynamics of the resource system and units, hence increasing knowledge, enabling prediction, easing decision-making and institution-

crafting (new infrastructures) to ensure long-term sustainability of the resource. This information may already have been acquired by a group of actors and this information can be transmitted to newcomers so that they can learn the trade properly.

Finally, actors may share information to deal with common threats. Common threats are the result of social dilemma situations which are linked to decisions D of actors. This information can be shared to prevent others from adopting a behavior that would harm the resource. This type of information sharing could ensure conditional cooperation (or reciprocal altruism) by making sure that none is infringing a rule without sanction. To ensure this behavior, monitoring and sanctioning are useful goals of information sharing.

4.3.2 Information? What kind of information?

I consider information for [NRM](#) in general: all types of information that actors can exchange related to the management of their professional activity and a resource they share. Environmental information take different forms, and is observed as such in case studies. Information can take the form of perishable pieces of data (weather forecast) or take the form of durable texts (a law). Table 4.3 lists information types that can be shared by users of a [SES](#). This list has been created using the literature on information sharing for [NRM](#). In the study in literature commons, I only give the most relevant paper that I found for concision. The topic of information sharing for [NRM](#) is widely studied, even though not systematically. This table shows that a vast diversity of subjects are embedded within the concept of information.

Apart from the type of information, several levels of aggregation can be thought of. Suppose the shared information consists of values $x_a, a \in \mathcal{A}$, where \mathcal{A} is a set of actors. Here is a list of possible strategies to disseminate information: a global aggregated indicator, *i.e.* a value $y = f(\{x_a\}_{a \in \mathcal{A}})$, for instance the average of given values; a distribution of values $\{x_a\}_{a \in \mathcal{A}}$; the values associated with the actors who provided the information $\{(a, x_a)\}_{a \in \mathcal{A}}$. Thus, knowing the type of information is not enough to describe information sharing. The way it is presented is to be taken into account as well. Depending on how information is presented, decisions that can be made using the information and participation in the system can vary widely (Section 4.6).

4.3.3 How to share information?

How is information shared? Information needs to be emitted and received. Information can be stored in an artifact located in a facility or be evanescent, disappearing except in the minds of those who told it and those who were present at that time.

Three main categories of emitters and receivers can be defined: a person (1), a group of people (n) and an institution (I). We can thus define nine

Table 4.3: Types of information shared for NRM.

Information type	Examples	Example study
Environmental data	Water temperature, rainfall	Allen and Kilvington (2005)
Resource units marking	V-notched lobster	Acheson (2003)
Decisions	Quantity of water used	Anderies et al. (2011)
Outcomes, payoffs	Quantity of fish caught	Haynie et al. (2009)
Knowledge	How to grow carrots	Cutts et al. (2011)
Beliefs	Sharing information increases mutual understanding	Adams et al. (2003)
Technology, innovations	New cultivation technique	Pyka et al. (2007)
Issues between users	Conflict over land-use	
Hazards	Virus, pollutions	Cutts et al. (2011)
Rules	Sign at entrance	
(Mis)behavior	Cow exposed in village	Ostrom (1990)

types of relations between emitters and receivers, all combinations of these three categories which are illustrated in Table 4.4. These combination call for different means to share information.

The most informal way to share information is through speaking. Exchange of information in such a way can range from formal, as during meetings, to most informal, from tutor to apprentice, or during an evening in a pub. This type of information sharing can be studied using social networks studies when one wants to understand the impacts of this type of information diffusion ([Bodin et al., 2006](#)). Some authors even wondered if “what you know is who you know”, studying this question using social networks ([Crona and Bodin, 2006](#)).

4.3.4 Conclusion on why, what and how

In this section, I have shown that information is ubiquitous, serves a wide variety of purposes, from predicting the resource dynamics, to influencing rule-crafting and favoring conditional cooperation. Information is spread through channels that are of different nature such as social networks, schools or information sharing artifacts.

By insisting on the vast diversity of the information realm, simply within the field of [NRM](#), I wish to show to the reader the intrinsic difficulty of studying the subject of information and information sharing as a whole. Consequences of information sharing are debated, effects can be subtle and little changes in how

Table 4.4: Means to transfer information from column to row type of actor. '1' represents a single person, 'n' a group of people and 'I' an institution.

Receiver	1	n	I
Emitter			
1	Interpersonal communication, personal email	Collective email	Court of law
n	Informal meeting	Meetings, information sharing systems	Class action
I	Court of law, official letter	School, signs, court of law, leaflets, information sharing system	Court of law, negotiation

information is shared (such as different granularities) may lead to important differences. Being so vast a subject, one needs to make assumptions and beware of drawing definitive conclusions, keeping in mind the idea that there is no panacea. Even studies that claim to explore information sharing for [NRM](#) are actually focusing on specific types of situations which are studied in narrow contexts such as in experimental economics or case studies, or multi-agent simulation. One has to remain modest and prudent in one's intent to derive iron, immutable rules from these studies even though a cumulation of evidence may help in finding generalities, such as in [Ostrom \(1990\)](#).

Despite these limitations, it is possible to study specific information sharing elements and understand how they may influence a system. I delve into the subject of information sharing through the angle of information sharing artifacts as a means to address threats ([Chapter 3](#)), without setting aside important information sharing means such as diffusion through real networks.

4.4 Local information sharing artifacts

4.4.1 Description

Considering the wide latitude of possible information sharing artifacts, a clear specification of the main elements of the artifacts, as much as in content as in goal, is needed. Elements cited in the previous sections of this chapter demonstrate that properties of information sharing artifacts, access rules and types of information (ideas) put in the system matter and can change how the system will be used.

A list of items that should be taken care of follows. In this list, I use the word information in a manner that encompasses data and information in the DIKW pyramid. All combinations of items can exist and could be tested. I

will show some combinations that seem more likely to give results than others for specific types of threats in Section 4.5. In this thesis, I investigate a few of them. Section 4.6 contains a brief review of studies found in the literature.

Goal What is (are) the goal(s) for setting up the information sharing artifact? What questions should the artifact answer to?

Type What type of information does the artifact contain?

Write Who can enter information? Does anyone even enter information? This element ranges from automatic input from sensors to users entering figures or collectively writing texts.

Read Who can read information? It can be limited to users providing information, to all users, to some kinds of categories of population (users of several profession and / or public servants), or be open to all.

Granularity What grain of information should reader have access to? Should they be able to have access to each and every piece of data entered by everyone, or should they access only aggregated information, single values or distributions? Differentiated access rights may be considered.

Dynamic Is information updated constantly (weather forecast), or does it gather stable information valid for longer (legislations, techniques)? How important is it for information to be recent and up-to-date?

Those items are important to take into consideration when designing or studying an information sharing artifact. These elements can be combined as part of the information being accessible to some users, while other parts are accessible to another category of users. Goals can be combined and multiple: having up-to-date information about some flows could help warn users of an incoming threat, limiting its short term effects and help learn its origin and mitigate its effects in the future.

4.4.2 Evaluation

Let us suppose that some actors \mathcal{A} are facing a threat. The threat may originate from or concern other types of actors. How to evaluate consequences of the implementation of information sharing artifacts (a new piece of infrastructure) for actors of and out of \mathcal{A} ? What difference and for whom do the artifact make? According to actors' or analysts' goals, evaluating differences could be done using qualitative or quantitative methods.

ENCORE is an observation and evaluation framework for participatory management processes (Ferrand, 2004; Daniell, 2012). It is a useful framework to list possible evolutions linked to a process involving a number of different actors. It is an acronym of the following terms: *External* – Improvements in \mathcal{C} .

Normative – Norms, values and preferences of actors. *Cognitive* – Representations and beliefs of actors. *Operational* – Decisions D of actors. *Relational* – Social relationships between users. *Equity* – Perception of social justice. The definitions have been adapted from Daniell (2012) to fit the situation studied in this thesis. This framework can be used by actors or planners of \mathcal{A} to predict or identify differences the artifact could lead to. The ENCORE framework provides qualitative dimensions. These dimensions can be deemed sufficient for actors, especially when the information sharing artifact is destined to create hard to measure effects.

If one would like to evaluate the differences created by implementing an artifact in a more quantitative manner, one can create an agent-based model, a model of a situation where agents interact in an environment (I provide a thorough description of the method in Chapter 6). One can then set up indicators to measure characteristics of the environment and actors and compare situations with and without the artifact.

4.5 Information sharing stakes for threats

In this section, I investigate the relation between threats and stakes raised for users in terms of information sharing.

4.5.1 Public threat

If the threat is public, users need to reach external actors or external factors and thus to broaden the view and action capacity. Building information sharing systems can then help act beyond the usual scope. In this sense, users need to build very open boundary objects, so that information can be understood and shared with publics from different background, especially when the targeted audience is the general public. Information sharing can help users of the resource communicate threats, including characteristics \mathcal{C} of assets, that actors' (not necessarily in \mathcal{A}) decisions D pose to their usage, legitimate actors of \mathcal{A} 's role and increase awareness, fostering some specific actions and changes in D. A strategy to make the threat internal could be to try to change the system scale. By redefining the scale, users could make an external threat internal, especially when involving other types of actors. Information sharing artifacts may be used to change threat type by making the internality dimension evolve.

Given these elements, an information sharing artifact dedicated for tackling the threat at its source should have the following requirements: writing does not have precise requirement, but reading should be open-to-all, the granularity level should probably be high with no need for details, and it does not need to be highly dynamic.

In this case, I adopt a long term view, a way for actors to limit the effects of potential threats. It is also possible to consider an incoming threat that has to be dealt with. The information system should be able to warn users of the

imminence of the realization of a threat. Then, information should be much more dynamic and up-to-date.

4.5.2 Private threat

If the threat is private, information sharing can help in spreading knowledge. Users do not all have the same experience, age nor network. They do not necessarily have the same skills and do not all have the same known-how or even the simple awareness of threats facing them. Their decisions D may be unadapted, for them and/or for the resource. Gathering information in information systems can have the impact of speeding up learning, sharpening strategies, or making thinking clearer around investments. “Experience is the main source of information” (Apesteguia, 2006, p.56). This kind of information and knowledge sharing faces issues of free-riding, where some actors use information without bothering to help creating the artifact and strategic behavior, such as users retaining information about a technology, or even patenting an invention. In *SESS*, actors are at the same time competitors and collaborators.

Threats can be linked to (collective) lack of knowledge about environmental dynamics E , as well as determinants of the evolution of \mathcal{C} . Dynamics could be better understood if users shared their own decisions D and outcomes when scientific investigations are non existent, too scarce or non adapted. In this kind of case, actors could be forced to participate by creating a club artifact, excluding users from results if they do not provide information. It seems that since actors know each other, or at least a subset of them, it would be difficult to prevent information from leaking out of the system.

This type of threat is internal, thus writing and reading should probably be limited to users of the resource. Accessibility to external actors would be of little interest. Goals could be multiple: from spreading knowledge (in this case the threat concept would be a bit far fetched), to gaining information about ill-known threats linked to some practices for instance. In this case, general and anonymous knowledge is sufficient, including rules and regulation communication, practices or relation between actions and outcomes.

4.5.3 Common threat

Common threats are those traditionally considered in studies on *CPRs*. Common threats are close to social dilemmas (Section 2.2). Actors have personal interests at odds with the general, which is their own in the long run. Tackling public threats is a coordination issue, where personal and collective interests of actors are aligned (although perhaps not their dedication to participate in collective action). To address common threats, users must fight their own instincts towards reaping short-term benefits. The main goal of an information sharing system should then be: favoring conditional cooperation. Information

could reveal practices in D and show respect of collective agreements by others, increasing chances of cooperation.

In these situations, second-order dilemmas emerge. Free-riding can occur when actors publicly show an intention to adopt a practice and secretly adopts another one, more in favor of his interest. The mere existence of information systems is actually not sufficient to solve these collective dilemmas. As much as a game theoretic analysis cannot help solving tragedies of the commons and escape nasty Nash equilibria, an information sharing system subject to the same kind of dilemma cannot offer a solution in itself. Without being specific, information about practices is not enough. For instance, seeing a distribution of anonymised data about practices can reveal non cooperative behavior, but can it favor cooperation? Does knowing the existence of free-riders favor cooperation? It seems doubtful and confirmed in [Janssen \(2013\)](#).

We must turn to the study of building trust, and how an information system can favor building trust, in others and in the information. It can be the case that the very process of creating the information sharing artifact itself increases conditional cooperation by getting people to know each other and collaborate on a common project.

This kind of threat is the most studied in the literature, because of its link to collective dilemmas, a kind of dilemma scholars are eager to explore.

Thus, the three types of threats are associated with radically different stakes: reaching outer actors, increasing experience, or ensuring alignment between personal and collective interest.

4.6 IS for NRM in the literature

An important body of research on impact of information in the context of NRM exists. This research draws on several methodologies such as case studies, experimental economics or [Agent-Based Modeling \(ABM\)](#). Studies use descriptive (*e.g.* [Paget et al., 2016](#)) or normative approaches (*e.g.* [Villena and Zecchetto, 2010](#)), or a combination of both (*e.g.* [Haynie et al., 2009](#)). I selected a set of relevant studies and place them in the space of goods, threats and information. I subsequently give results in [Table 4.5](#).

A majority of studies are focused on [CPR](#) management mixed with a common threat. This combination is one of the main topics of the study of commons. This focal interest is logical considering that in these cases, researchers are looking at a problem that is mostly closed, which solution consists in finding ways, such as information sharing, to change a payoff by creating adapted institutions.

Types of information may concern a single aspect of threats such as actors (irrigators) in [Bell et al. \(2015\)](#) who get information on water flows (from E); or a combination of elements such as in [Villena and Zecchetto \(2010\)](#) where actors (theoretical players) share information about personal efforts (D) and

Table 4.5: Studies of information sharing in the context of NRM

Resource	Threat	Component	Information	Methodology	Results	Source
Irrigation (CPR)	Common: Inequality in water distribution	E	Flow information	Case study, Experimental game	“Flow information allowed players to take more effective action to target overuse, and overall activities that might bring social disapproval were reduced with information.” But no improvement in equity	Bell et al. (2015)
Water (Public)	Public: water quality	$\mathcal{A}, \mathcal{C}, I, D$	General information, threats	Case study	Farmers managed to gain role as stewards over the resource they need	Paget et al. (2016)
Theoretical CPR	Common: Overuse / exhaustion	D	Subject-specific efforts	Experimental game	Great variations depending on settings but information is a core factor	Janssen (2013)
Wild fish (CPR)	Private: Spend too much to know location	E	Share locations	Game theory, Bayesian learning	“The benefits from information sharing are largest when congestion penalties are large, when information transmission among fishermen is costless, and when information about the true location of productive fishing sites does not quickly decay.”	Evans and Weninger (2013)
Theoretical CPR	Common: Overuse / exhaustion	\mathcal{C}, D	Subject-specific efforts and payoffs	Game theory, Econometrics	This kind of information worsens the tragedy of the commons	Villena and Zecchetto (2010)
Wild fish (CPR)	Common: Bycatch	D	Bycatch	Case study, Econometrics	“Conditionally cooperative behavior is prevalent but deteriorates as bycatch constraints tighten”	Haynie et al. (2009)
Theoretical CPR	Common: Overuse / exhaustion	\mathcal{C}	Pay-off structure or not	Experiment, Game theory	Aggregate behavior is not significantly different pay-off structure is available or not	Apesteguia (2006)

get information about characteristics of the resource (\mathcal{C}) in a payoff matrix.

Knowing the type of information on threats that actors share is once again not enough to conclude with certainty on the difference (if there is one) created for actors. In three studies where actors share information on their practices (\mathcal{D}), conclusions are different: Haynie et al. (2009) show that conditional cooperation increases until resources are too depleted; Villena and Zecchetto (2010) demonstrate that information on subject-specific payoff worsens the tragedy of the commons; and Janssen (2013) conclude that results vary according to settings.

4.7 Conclusion

Information is a versatile, multi-purpose, and difficult to define good. In this chapter, I have first evoked general stakes about information in modern days, which changed dramatically with the emergence of new artifacts (information technology). Then, focusing on [NRM](#), I have shown that there are specific challenges for information sharing at local levels, in this context where users are competitors and cooperators at the same time: limited anonymity, strategic behavior, free-riding and monitoring.

Even though information may be shared through social network and existing institutions, when they need to face a threat, actors \mathcal{A} may build an artifact as a new infrastructure in I . Artifacts may be used to face threats of all types by collecting or sharing information of diverse types, for instance environmental dynamics \mathcal{E} , decisions \mathcal{D} or outcomes. To create such an artifact, specifications on the goal, type, granularity and dynamics of information, access in writing and reading need to be defined clearly. These stipulations vary according to the type of threat actors face and the targeted audience of the artifact.

Studies on information in [NRM](#) are not converging towards general statements such as “information leads to better resource management”. They rather show a diversity of consequences, from situations where information leads to better outcomes for actors and resources to others where the general situation deteriorates.

State of the Art - Conclusions

The three chapters of the State of the Art section are designed to articulate three main topics that are necessary to investigate while studying information in the domain of [Natural Resources Management \(NRM\)](#): goods and resources; threats; and information (sharing).

I have shown in Chapter 2 the importance of a fine distinction between different types of goods and resources to understand with precision issues and stakes that are relevant so as to manage the said good or resource. Two main properties have been defined to characterize a good type: subtractability and excludability. These properties opened the door for the description of four main types of goods: private, club, public and [CPRs](#). [CPRs](#) are subject to the tragedy of the commons, an instance of social dilemma, at least theoretically and in some cases around the world. Focusing on conditions for sustainable management for [CPRs](#), researchers have extended their investigation to coupled human and natural systems and designed and improved the [Social-Ecological System \(SES\)](#) framework (Figure 2.2 and Table B.1).

The [SES](#) framework gives a thorough description of a system where some actors interact with a renewable resource (a resource system) from which they can subtract resource units. Actors and public authorities are organized in a governance system. These elements are in interaction and result in some outcomes that feedback on those entities.

In Chapter 3, I described an element that is lacking from the [SES](#) framework, while lying at the core of [NRM](#): threats. Threats are related, but do not coincide with close concepts such as hazard, risk or vulnerability. I propose to define a threat as a 5-tuple $\langle \mathcal{A}, \mathcal{C}, I, \mathcal{D}, \mathcal{E} \rangle$, actors \mathcal{A} using assets (goods or resources), some characteristics \mathcal{C} of which can be damaged by infrastructure I as well as by environmental dynamics \mathcal{E} , actors decisions \mathcal{D} that can either affect directly \mathcal{C} or indirectly through I (Table 3.1). These elements allow for a description of threats, but are not sufficient to define and identify strategies to cope with them in a general way.

With this goal in mind, I defined two properties, internality and excludability, that enable the identification of three main types of threats: public (low internality and excludability), private (high internality and excludability) and common (high internality and low excludability) threats. Common threats to [CPRs](#) are the underlying threats that are usually studied in the theory of the

commons: exhaustion, free-riding. All combinations of threats and goods are possible (Table 3.5). I use this fact to advocate for the use of the threats typology to frame NRM questions in addition to the goods and resource usual framing. I adopt this vision for the rest of the thesis. Public threats require strategies that can reach beyond the group of actors themselves. These are threats that cannot be made internal by a simple change of system size: these threats are defined in systems that are open, or difficult to close. Private threats are usually linked with lack of personal or collective knowledge and are especially interesting to study in combination with information sharing.

I propose some modifications to the SES framework (Table 3.6) that explicitly take into account the threats that have been defined. Threats need to be put in the forefront since they lie at the center of interactions and difficulties linked with NRM.

Information sharing (Chapter 4) is a central element for NRM. Information is everywhere and takes a vast range of subjects and shapes, it varies in granularity or accuracy (Table 4.3), its existing and sharing has multiple consequences and is shared for numerous reasons (Table 4.2), through a wide variety of channels (Table 4.4). This ubiquity needs to be kept in mind while studying information sharing for NRM: one should not forget the complexity of information sharing, and of the systems in which this information is shared. Contradicting conclusions between studies reflect this ubiquity.

While there are multiple channels for information to flow through, an interesting point to focus on is a reification around more or less dynamic information sharing artifacts (external representations) that are deemed solutions to manage the resource better and are used increasingly. A study of artifact impacts needs to take into account other information diffusion media, in particular real social networks. Those artifacts need to be carefully described. Describing an information sharing artifact requires going through its goal(s), defining who can write and read information and in what granularity, as well as characterizing dynamic aspects (obsolescence) of the information. Information sharing stakes for the three types of threats are quite different. In the case of a public threat, information on C or D can be used as a feedback that allows a common understanding of issues and consequences of practices, as well as communication with actors who may have no particular direct interest for the resource. In this case, for the target, personal and collective interests are aligned. The case of private threats is interesting to study by coupling with information sharing. Private threats are related to lack of knowledge, information sharing may fill that gap by enabling actors to share knowledge on infrastructure I , on decisions D they make and/or related outcomes, or collect information about environmental dynamics E . Common threats exist in situations of social dilemmas. They are the initial threats that have been studied along the development of the field of research on commons and information on environmental dynamics E and human decisions D may help favor conditional cooperation and respect for institutions.

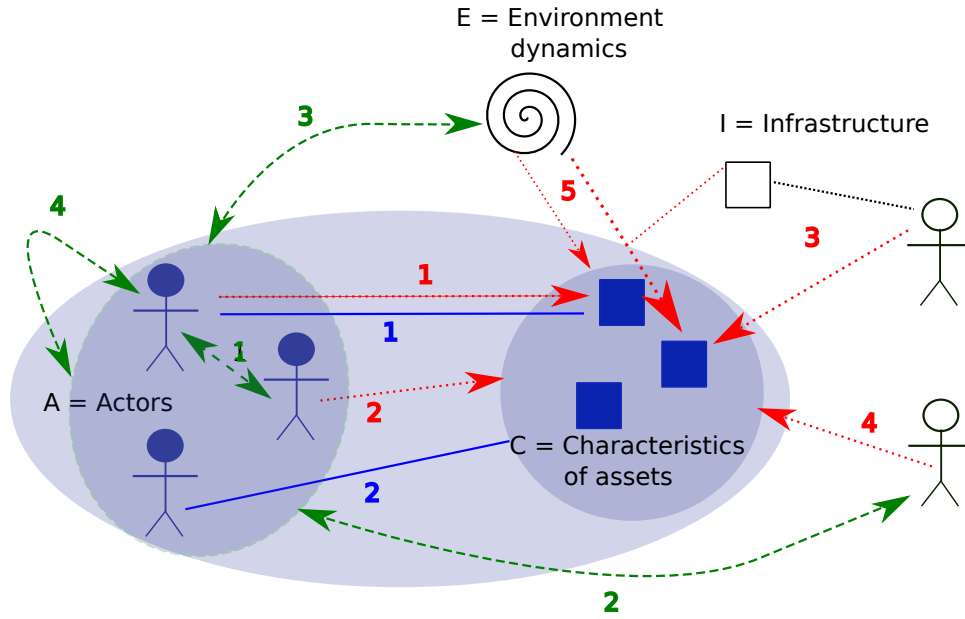


Figure 4.3: Interactions around threats. Blue solid lines represent use or possession, red dotted lines, threats and green dashed lines, information sharing possibilities. Information artifacts are not represented, but they can be placed in the path of each green dashed line.

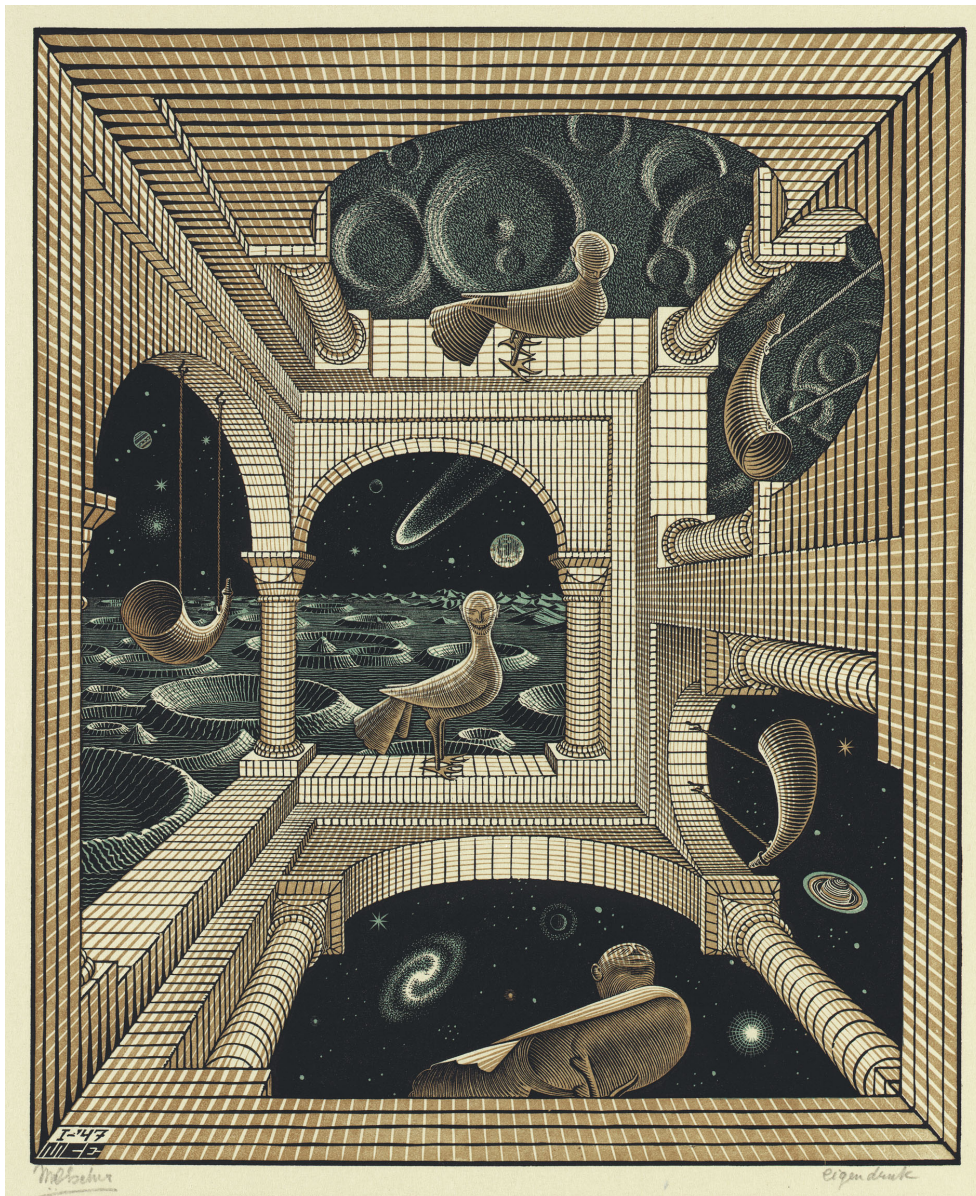
Figure 4.3 articulates the different elements that appear throughout Part I. Blue (filled) actors are a set of actors \mathcal{A} that are linked to assets, either as a collection of private goods (such as a collection of private boats) or a more global resource (such as a resource system). The blue (plain) lines show this connection with divided goods (1) or collective assets (2). Threats happen and may impact characteristics \mathcal{C} of assets. They are represented with red dotted arrows, coming from an actor to their private good (1 - private threat), due to lack of experience for instance or to a global resource (2 - common threat), adopting free-riding behavior. Public threats appear in arrows 3 to 5, with threats originating from other actors, from a combination of actors and infrastructure, or from some environmental dynamics, that may be combined with other elements. Information (green arrows) can be shared and used in several ways. Firstly, among actors of the group, with the intention of gaining knowledge, or solve conflicts. Secondly, the group of actors may send information to external actors, or the other way around, to limit the impact of public threats. Thirdly, sensors can be designed to measure, understand and limit the negative impact of environmental hazards. Fourthly, information can be shared from a member of the group to the group, or from the group to a member of the group, mostly to deal with internal threats.

I use these theoretical elements applied to case studies on oyster farming, in

the Thau Basin, France and in several estuaries of [New South Wales \(NSW\)](#), Australia, focusing on public threats (water quality) and the strategies, in terms of information or not, deployed by the actors to cope with them. An agent-based model follows, based of the understanding of ill-understood environmental dynamics (a virus *modus operandi*), to study the consequences of information sharing for a private threat. I first describe the methodology that I followed in Part [II](#), then I present and compare the case studies in Part [III](#), discuss the results in Part [IV](#), and conclude in Part [V](#).

Part II

Methodology



Introduction to the Methodology

Depending on the goal of the researcher, a toolbox of methodologies exist. [Janssen and Ostrom \(2006\)](#) classify those methods according to two main dimensions (Figure 4.4): (a) is the study contextual or general? (b) does the study include few or many subjects?

According to their classification, case studies are contextual and may include many subjects. Role-playing games are contextual and include few subjects around the table. These games usually involve local actors who play their roles or roles played by others in their own context such as a member of a local monitoring agency playing a farmer. Games may be played around a table using a specifically designed board game or using a computer-based model where actors enter their decisions. A more generalized version of these role-playing games feature laboratory experiments where researchers usually investigate a question by designing an experiment played by students in an abstract situation, for instance [Janssen \(2013\)](#) follows situations where 2 or 5 students endowed with different types of information. A last method to study generalized situations involving many subjects is the study of stylized facts, through statistical methods, or using modeling such as [Haynie et al. \(2009\)](#) who use econometric modeling and game theory derived from a case study analysis.

Among those methods, I had to choose. The question of the thesis is: how can actors of [Social-Ecological Systems \(SESs\)](#) face threats by sharing information? The “no panacea” warning prompted me to choose to explore a descriptive and contextual approach in specific coupled human and natural systems where actors have implemented actual artifacts. For the context, oyster farming seemed (and proved to be) an interesting option since oyster growers depend heavily on a resource, water in estuaries, on which they have little or no direct control. They act in intrinsically open systems and are subjects of threats of all types. Information sharing is therefore a possible way for them to gain influence over this resource.

Relying on a single case study would have been a drastic limiting factor to findings generalization and put the identification of conclusions at risk ([Poteete](#)

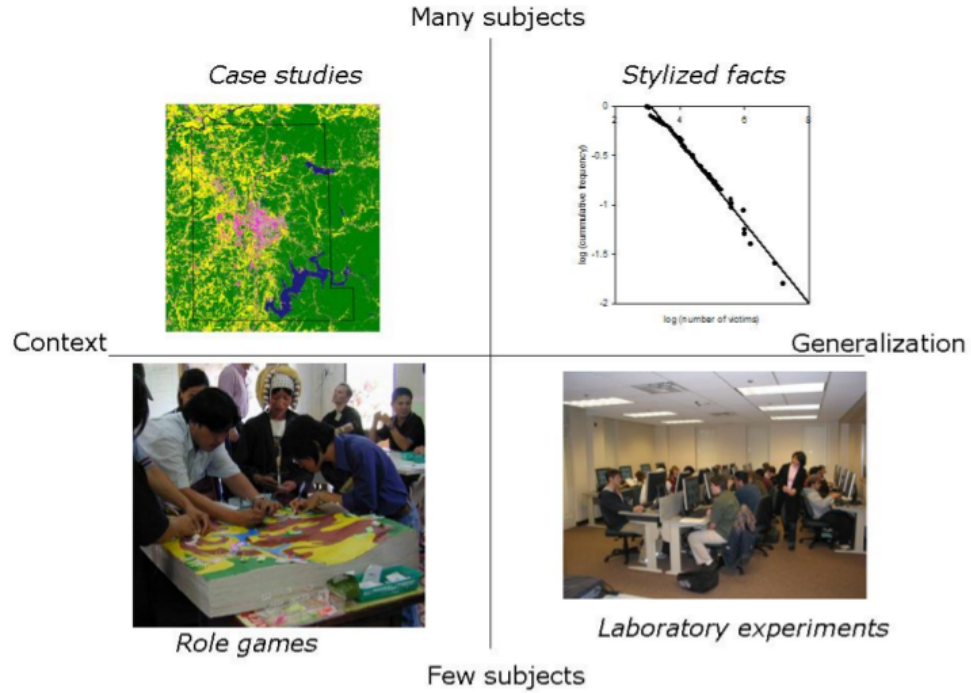


Figure 4.4: Methodologies available for research in NRM ([Janssen and Ostrom, 2006](#)).

[et al., 2010](#)). Thus, I made the choice of investigating two different settings in which growers farm oysters: one estuary in France and several in [New South Wales \(NSW\)](#), Australia. Chapter 5 provides more information on the specific case studies that I chose to explore as well as the detailed methodology.

The study of information sharing artifacts consequences on threats impacts is difficult to grasp within the time frame of a thesis. Information and information sharing are subtle to measure, participation is difficult to observe, and changes may arise in the long-run in non-reproducible settings. Therefore, I could not solely rely on case studies. I had to find a more direct way to explore the information sharing question that allows for exploration of controlled scenarios. The use of an agent-based model is advised in such conditions ([Bonté, 2011](#)). The case study investigation revealed a problem farmers had little capacity to deal with, a virus attacking the oysters. I studied the question of how useful an information sharing artifact may be by designing an agent-based model on this question. Would more information lead to better results for the resource and for the actors? Agent-based models are introduced in Chapter 6.

Chapter 5

Methodology for Case Studies

To investigate the questions of this thesis, I dwelt upon two case studies on oyster farming: one in the Thau Lagoon, France and one in [NSW](#), Australia. I explored the case studies by interviewing actors, participating in meeting, creating a survey and reading official and gray literature. First, I motivate the choice of these specific cases of oyster farming. Then, I detail the methods that I followed to gather information about the cases.

5.1 Case choice

In this section, I explain why I chose to investigate the specific cases of the Thau Lagoon, France and several estuaries in [NSW](#), Australia. In both cases, information sharing systems had been or were in the process of being implemented, by actors or by public authorities, regarding directly oyster farming or more generally water management.

Despite challenges linked to the investigation of several cases ([Poteete et al., 2010](#), Chapter 3) and the limited time frame of a thesis, I decided to investigate two distinct cases, based on the same kinds of farming practice, oyster farming. This choice enables comparison and is a step towards generalization. Relationships and insights learned from a single case could prove too much intertwined with a local reality. As put by the authors, context matters to explain results of experiments ([Castillo et al., 2011](#)). As a corollary, studying several cases may prevent one from being too context specific. Comparing with a second case helps limiting these constructs and sometimes even allows the identification of key elements that would explain why something is true in one case and false in another.

The first case is located in the Thau lagoon, in the South of France, and the second one is located in [NSW](#), Australia, involving the exploration of several estuaries. These two precise cases were first identified and chosen thanks to an already existing network of researchers acquainted with both the cases and local actors, simplifying entry and investigation, important elements in

the time frame of a thesis. In France, there is a long history of collaboration between IRSTEA and local authorities of the Thau Lagoon. Specifically, Dr. Pierre Maurel, one of my tutor, worked and keeps working on the Thau Lagoon with local actors (Maurel, 2012). In NSW, Dr. Katherine Daniell, former PhD student at IRSTEA and LAMSADE, researcher at the Australian National University Center for European Studies (ANUCES), has extensively studied the Hawkesbury river (Daniell et al., 2010; Daniell, 2012). Her network in the local community quickly opened many doors, speeding up the field study process.

The existing network is simply a first motivation that provides useful entry points. Adding to this, these cases were relevant in the context of information sharing. In the Thau Lagoon, local authorities have been developing the OMEGA Thau project since 2007. This project aims at building an information system to monitor closely water quality and water flows in the whole Thau catchment. Oyster farmers have been involved in the project from the beginning. In NSW, oyster farmers developed estuary-wide environmental management systems that they use to gain clout in their local contexts. The question of the use of information and information sharing in those cases is thus relevant. These artifacts are described in detail in Chapter 8.

5.2 Interviews and participatory observation

This section contains the protocols that I followed for the field investigation. I describe it using a chronological approach. Statistics are summed up in Table 5.1. The field work has first consisted in getting acquainted with the Thau Lagoon situation, and more generally with oyster farming. Then, I researched the NSW situation. Finally, I got back to the Thau Lagoon to use the knowledge acquired in the Australian context to broaden comparison.

5.2.1 Thau Lagoon

Chronologically, this case was researched first. I first got acquainted with it by studying gray literature, official statistics and general global presentations of the area provided by the very active local council.

Important sociological work exists, especially centered around fishing with large parts on oyster farming in the Thau lagoon (Giovannoni, 1995; Sécolier, 2009). These books are useful to immerse oneself into local traditions and relations between groups of actors. Statistical socio-economic studies are numerous, both on the Thau catchment, oyster farmers and oyster production. In the beginning, the field work consisted in participating in three meetings held by the local council (Section 8.2.2). These meetings took place to prepare visits to oyster farmers, and to make the council acquainted with the subject, while exchanging on local information and sharing stakes. From the first meeting onwards, I was in regular contact with this local council. Then,

Table 5.1: Statistics for field studies investigation.

Case study	Thau	NSW
Estuaries visited	1	9
Growers interviewed	17	13
Growers	500	320
Workshops attended	1	1
Meetings attended	5	0
Non-growers interviewed	1	3

I interviewed 17 oyster farmers (out of 500) using semi-structured interviews. The interviews were semi-structured in order to allow interviewees to express as much elements as possible, without setting too many constraints. Generally, I tried to organize the interview using the following outline:

- Describe your practices, oyster farming in general and local conditions.
- Explain your involvement and your vision of oyster farmers' role in water management.
- Describe your relations with other oyster farmers with a special focus on information sharing and the OMEGA Thau project.

In the beginning, I chose to emphasize the microbiological threat which is the focus of the information sharing system developed by the [Syndicat Mixte du Bassin de Thau \(SMBT\)](#) (Section 8.2.3.1) and soon broadened the question to other types of threats. These main themes were backed by questions that would be asked or not, depending on how available the interviewee was, and on his/her previous answers. The questions order depended on what direction the interviewee wanted to follow during the discussion. The shortest interview lasted for 10 minutes, most of them lasted for 45 min to 1 hour. Two oyster farmers gave more than 3 hours of their time to this process.

Some people that I interviewed were recommended by interviewees. I conducted most of the interviews by choosing an area, walking along the shores where the sheds are located and asking whether someone would answer my questions (Figure 5.1 gives the spatial distribution of interviewed farmers). This random procedure ensures as much heterogeneity among interviewees as possible. Most sheds were empty when I walked by and I have been turned away by some farmers, while others were more welcoming and have accepted to be interviewed. Most interviews were conducted in the morning, while oyster farmers are on their sheds, sorting and cleaning oysters. The sheds are generally empty during afternoons and farmers go out on the water in the early morning. Thus, the window of opportunity is quite limited.

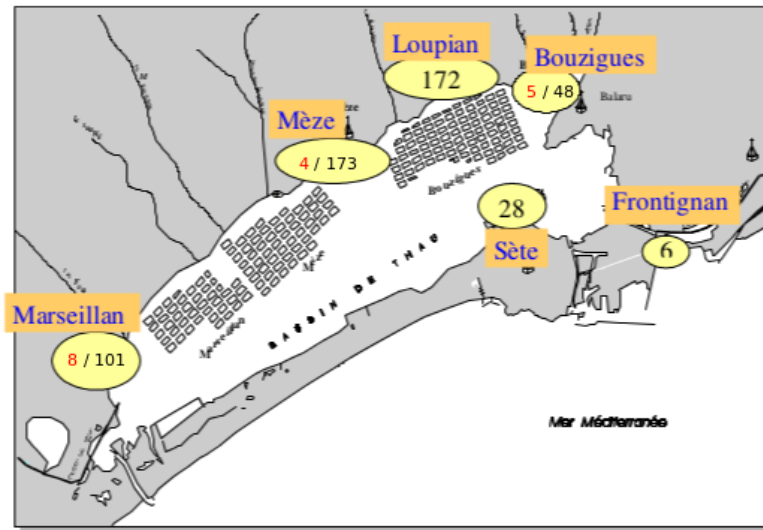


Figure 5.1: The Thau lagoon sheds. In black, the total number of oyster farmers, in red, the number interviewed (Adapted from [SMBT, 2009](#)).

Among these 17 growers interviewed, most owned small, family-size farms, with 5 or less tables. Two of them were part of bigger businesses, with up to 30 workers and 46 tables. At least 3 of them ran a restaurant in parallel. Some were newcomers, with less than a year of experience, others were old timers with more than 30 years in the business. One oyster farmer was a member of an association dedicated to promoting traditional methods of oyster farming: *Ostréiculteur traditionnel*¹. One of them was an ex-researcher at [Institut Français de Recherche pour l'Exploitation de la Mer \(Ifremer\)](#), the French Institute for Marine Studies, who wanted to work in a more hands-on environment. An oyster farmer was of special importance during the investigation. I met him several times for interviews. He is involved in many different arenas (notably water management ones), and organizes the commission on environment at the local oyster farming institution, [Comité Régional de la Conchyliculture de Méditerranée \(CRCM\)](#) (Section 8.2.2).

Further to these interviews with growers, I interviewed the director of [CRCM](#) to understand better relationship of the lobby with grassroots farmers, other local professional or political institutions and as well his views on information sharing and information sharing artifacts. I also attended a meeting of the commission on environment, held at [CRCM](#), involving 7 oyster farmers and 1 oyster farmer / fisherman. This meeting helped to understand the position of local growers as actors of the local [SES](#) and how they manage to obtain information and act.

The result of these investigations led to a view of how local oyster farmers

¹<http://www.ostreiculteurtraditionnel.fr/index.html>

could use information sharing, and especially information sharing artifacts, to help manage their resource, at the collective and at the personal levels (Part IV). In the end, microbiological issues seem to be of less concern to growers than a virulent virus wreaking havoc on crops since 2008. At that point of the investigation, it was unclear how information sharing artifacts could lead to improvements in resource management. The second step of the process was then to investigate a second field.

5.2.2 New South Wales, Australia

This part of the investigation was led on a shorter period of time, during a three months stay in Australia from October to December 2014. The initial project was to focus on a single basin: the Hawkesbury River basin. However, when I went to the Hawkesbury, only 3 oyster farmers remained out of the 12 that were growing oysters in 2012. They were struck twice by virulent viruses attacks that wiped them out. The most recent attacks started in 2013. It was obviously impossible, or at most uninteresting, to compare two information sharing situations, with 500 farmers on one side and 3 on the other.

Still, one element came out of these interviews with local farmers: after having been struck by the first virus which lowered the local oyster grower population from 25 to 4 (it rose up again to 12 in 2012 and dropped to 3 afterwards), the remaining growers gathered and started implementing an [Environmental Management System \(EMS\)](#) at the estuary level. These growers were proud of their [EMS](#), saying it was the basis for a great relation they maintain with the local council, another very proactive council.

These elements seemed a good entry point to study information sharing as interviews led to understand that [EMSs](#) were developed in more than half (17 out of 32) estuaries of [NSW](#).

The number of oyster farmers in [NSW](#) estuaries is much less than in the Thau lagoon, with 1 to 30 oyster farmers per estuary. For this reason, I decided to interview a small number of oyster farmer in several estuaries rather than interviewing all oyster farmers in only one or two in order to create a better picture of the case study.

Apart from the 2 growers interviewed in the Hawkesbury River (out of 3 licensed farmers), I interviewed 1 (out of 10) grower in the Shoalhaven River, then I interviewed 3 (out of 7) growers in Wagonga Inlet, 1 (out of 10) in Wapengo Lagoon, 1 (out of 1) in Nelson Lagoon, 3 (out of 6) in Merimbula Lake, 1 (out of 24) in Pambula Lake, 1 (out of 8) in Wonboyn River. This makes 13 interviews. Licensed farmers are farmers who are authorized to grow oysters, they do not necessarily effectively farm oysters. Figure 5.2 shows the location of the estuaries that I visited. Sydney is located on the Georges River. In all these estuaries, [EMSs](#) were implemented, except Nelson Lagoon in which it was in the process of being implemented. Aside from the Hawkesbury, all these estuaries are located in the South Coast (*i.e.* South of Sydney), where

further studies were carried out as detailed above. I later learned that the situation was less problematic in the South Coast than in the North Coast. At that point, it was already too late, and due to time constraints, I could not lead a proper investigation in the North Coast. Despite this limiting factor, the South Coast situation was rich enough and worth investigating, as the rest of the thesis will demonstrate. Refer to Table 5.1 to get summarized figures regarding the investigation.

Some of the growers interviewed are proactive growers, keen on playing a leadership role for the industry. Among those, some are very involved in environment protection matters, such as the Bega Valley Shire EMS officer (from Bermagui River to Pambula Lake) or one who implemented an EMS at the individual farm level. These growers played a significant role in the adoption of EMSs involving all farmers in each estuary. Other growers were randomly chosen. Respondents were all rather smallholders owning a few tables. Their equipment ranged from basic and hand operated to state-of-the-art sorting machines. Almost all estuaries of the South Coast are equipped with EMSs. The only estuaries that are not yet equipped are small ones with only one or two growers.

These interviews were organized according to the following three points:

- Describe your practices, oyster farming in general and local conditions.
- Explain your involvement and your vision of oyster farmers' role in water management.
- Describe your relations with other oyster farmers with a special focus on information sharing and the OMEGA Thau project.

These semi-open interviews usually lasted for more than one hour and were all recorded with the interviewee's approval. These recordings have all been transcribed.

To get external points of view, I also conducted 3 other interviews with the author of another information sharing document, the [Oyster Industry Sustainable Aquaculture Strategy \(OISAS\)](#) (Section 8.1.3.1), member of the NSW Department of Primary Industries, with the [EMS](#) facilitator and with the Shellfish program manager of the [NSW Food Authority](#).

Some of the people I interviewed as well as others met in a workshop I attended called "The role of natural resources management in the NSW oyster industry" held in Sydney on November 26th, 2014. The idea behind this workshop was that "by sharing knowing and information, and improving communication across stakeholders, [it] will help foster stronger partnerships, and projects that deliver better outcomes for the industry and the environment" ([OceanWatch, 2014](#)). This workshop helped compensate the initial choice to head South by enabling the gathering of North growers points of view.

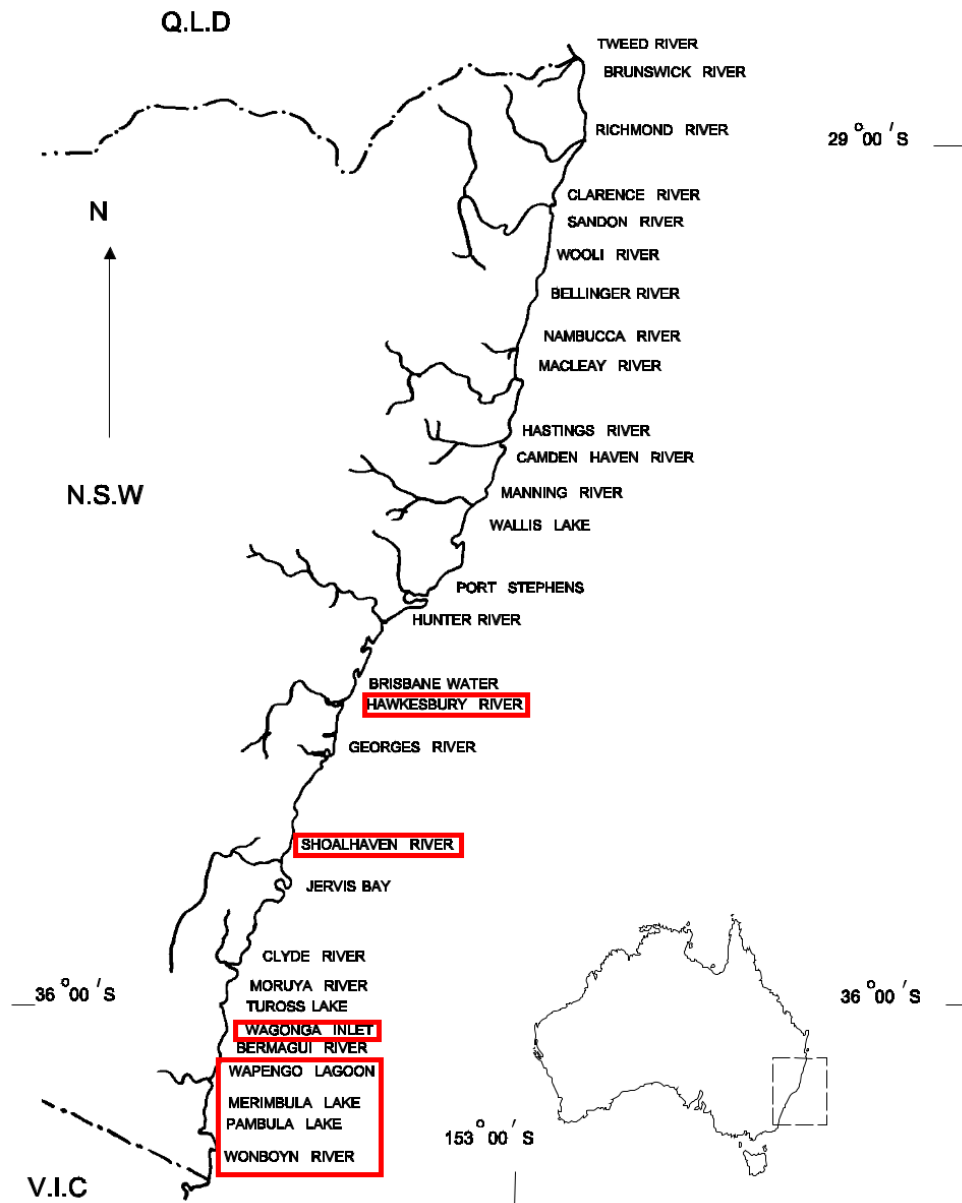


Figure 5.2: Estuaries where oysters are grown in NSW. Sydney is located in the Georges River estuary. Visited estuaries are squared with red rectangles (Adapted from OISAS, 2014).

5.2.3 Thau Lagoon, again

Once back in France, I presented the results of my investigation to two growers who were interested. I also intended to submit a survey to oyster farmers in the Thau Lagoon. Thus, I designed a survey. The survey was aimed at Thau Lagoon oyster farmers and is organized in the following way:

- Knowledge of local information documents (some of which I did not know the existence during the first investigation) and the use they make of them (those documents are presented in Section 8.2.3).
- Practices and involvement in water management as well as the role of oyster farmers in the estuary and the catchment.
- Interactions with local institutions.
- Personal data.

The goal of the survey was to obtain answers that would allow more extensive comparison on a quantitative basis.

A meeting was organized with the Thau Lagoon local authorities, with the attendance of CRCM director, and an Ifremer researcher. During this meeting, I presented the results of my investigation, focusing on the EMS part which seemed to interest those who were attending and suggested to launch the survey.

Unfortunately, the survey was not approved officially. I had to use unofficial ways to spread the survey. However, it did not prove sufficient. Only 20 people answered, among those, 7 answered fully.

5.3 Conclusion

In this chapter, I exposed the rationale for choosing oyster farming in the Thau Lagoon and estuaries in NSW. Those cases were chosen with two main reasons in mind: easy access thanks to an existing network and compatibility with the question of the thesis thanks to the existence of information sharing artifacts in both cases.

To investigate the cases, I dwelt upon 34 semi-open interviews with oyster farmers (17 in Thau and 13 in NSW) and local authorities (1 in Thau and 3 in NSW); used official and gray literature; and attended meetings and conferences using a participatory observation posture.

I realized that most information sharing in those artifacts were oriented towards water quality management (or more precisely deterioration of water quality mitigation), for a group of actors with limited capacity to act directly on their resource. Poor water quality is a public threat for oyster farmers. Interviews led to understanding that the main threat that oyster farmers are

currently facing is a virus, an internal threat. Little information sharing has been investigated on this question. I decided to turn to a method that allowed to create scenarios and investigate whether information sharing would lead to better virus management: [Agent-Based Modeling \(ABM\)](#). I present this method in the next chapter.

Chapter 6

Agent-Based Modeling

In the introduction of this part, I presented the idea developed by [Ostrom \(2007a\)](#) that there are no panaceas for [Natural Resources Management \(NRM\)](#). The same idea applies to methods: there is no panacea either for how to explore an object, especially such a complex one as information sharing (Chapter 4). It would be unreasonable to argue that a single approach is relevant and/or sufficient to investigate the subject. Except due to real-life constraints such as time, space and budget, there is no reason to limit oneself to that single approach ([Poteete et al., 2010](#)). Choosing a specific approach leads to shed light on specific angles of a situation, or to project some reality on a defined space that one can grasp.

I investigate the question of possible effects of information sharing for oyster farmers regarding a threat that they all suffer from: a virus killing their oysters. Does more information lead to better management and better outcomes for farmers? This threat is ill-understood (Part III) and the question of the influence of information sharing is hard to study and observe on the field. The time frame is long (the virus kills once per year), experiences cannot be repeated, and measuring precisely information sharing is difficult. Facing such a situation and questioning the idea according to which more information sharing leads to better results, it seemed natural to turn to [ABM](#). [ABMs](#), and their simulation, enable precise controlling of variables and tracking of trajectories in designed and reproducible scenarios.

A model can be used as a virtual laboratory in order to repeat a situation several times using various scenarios. [ABM](#) is a tool that enables exploring questions such as the one of this thesis ([Janssen and Ostrom, 2006](#)). [ABM](#) has been used in a wide variety of contexts at various scales, from epidemiology ([El-Sayed et al., 2012](#)), to markets ([Rouchier, 2013](#)), organizations ([Fioretti, 2013](#)), social-dilemmas ([Gotts et al., 2003](#)) or environment management ([Le Page et al., 2013](#)) among many others.

I first explain what an [ABM](#) is, what can be expected from a model and go through some advantages and limits of the approach. Then, I detail what is

intended by the term agent, and some of their key properties. Third, I investigate in more details the field of [ABM](#) for [NRM](#). To conclude, I go through the implementation details of [ABMs](#) with the description tools, [Unified Modeling Language \(UML\)](#) diagrams (class, sequence and activity) and [Overview, Design concepts, and Details \(ODD\)](#) protocol and the programming tools, [CORMAS](#) and [R](#).

6.1 What is ABM?

[ABM](#) is a method that allows to explore complex systems, and “offers a way to model social systems that are composed of agents who interact with and influence each other, learn from their experiences, and adapt their behaviors so they are better suited to their environment” ([Macal and North, 2010](#), p.151).

An [ABM](#) is a model in the first place. A model is an abstract representation of reality. [Minsky \(1968, p.1\)](#) provides the following definition:

“To an observer B , an object A^* is a model of an object A to the extent that B can use A^* to answer questions that interest him about A .”

This definition highlights that modeling is purpose-oriented and has to be considered as a projection. In our context, I need to clarify a few other concepts for which I give broad definitions (Adapted from [Treuil et al., 2008](#)):

Dynamic model A model that includes the structure of a reference system A as well as hypotheses or rules regarding the evolution of A .

Multi-agent system A dynamic system viewed as a set of agents evolving in an environment and having direct or indirect interactions. The multi-agent system paradigm is convenient as a transdisciplinary way of representing and studying [SEs](#) ([Bommel, 2009](#)). A formal definition follows in the next section.

Agent-Based model A model of the world structured as a multi-agent system.

Multi-Agent simulator An algorithm or program that can simulate the dynamics specified by the [ABM](#).

Multi-Agent simulation The activity of executing the simulator, resulting in simulation outputs that describe the evolution of the state of the [ABM](#) over the simulated period.

A comprehensive and recent overview of the state of the field can be found in the handbook *Simulating social complexity* ([Edmonds and Meyer, 2013b](#))

that provided elements of this chapter and that partly guided the creation of the [ABM](#) developed in this thesis.

In this section, first, I detail the general philosophy lying behind [ABMs](#) and the structure of a typical [ABM](#). Second, I discuss some advantages and drawbacks of this method.

6.1.1 “Micromotives and macrobehavior”

The title for this section is the title of a seminal paper in this field ([Schelling, 1978, 2006](#)) that explains clearly the philosophy behind [ABM](#). The main idea is to describe precisely how some entities, often called agents, interact in some kind of environment, and then understand how small scale decisions of entities (micromotives) and how their interactions affect globally this environment (macrobehavior). A specific attention is given on subjects such as feedback and emergence. This special attention forces the modeler to pay attention to the other side of the interaction: how macrobehavior influences micromotives.

This method is relevant for the study of complex systems since it enables to link two, or more, levels of the studied system. For instance, in his famous segregation model, [Schelling \(1971\)](#) describes a population of red and green agents, that I call people for now, who live in a grid representing a town. People know who they are living close to and have a certain tolerance level (their micromotive) formulated as: “I accept to have at most $x\%$ of the other type of population in my neighborhood, otherwise, I move”. The observed macrobehavior is the emergence of clusters of similar population, segregated neighborhoods, created by this simple behavior. Changes in the number of happy people, *i.e.* those who are below their tolerance level, is the feedback loop resulting from the observed macrobehavior ([Figure 6.1](#)). This model is an impressive attempt at understanding how neighborhoods are formed in towns without having to use macro arguments (such as planning) or to anticipate global behaviors since programming and describing the model only focuses on (simple) individual micromotives.

An [ABM](#) is composed of three main characteristics: the agents or individuals, their interactions and the environment in which they operate. Agents are discussed in details in [Section 6.2](#). Their interactions are defined through some kind of relationship resulting from an underlying typology. In the previous example, agents are interacting with their neighbor in this way: is my neighbor of my type? Formally, this [ABM](#) containing individuals moving in houses is represented as a cellular automaton, a grid that has a certain number of states and that react according to their neighbors state ([Conway, 1970](#)). With [ABM](#), it is possible to represent rich micro-processes and dynamic interactions, for instance through fix or evolving social network topologies on the set of agents that they use to exchange goods or information ([Amblard and Quattrociocchi, 2013](#)). Agents also interact with an environment that creates some constraints or opportunities. Agents can for instance be located in their environment, have

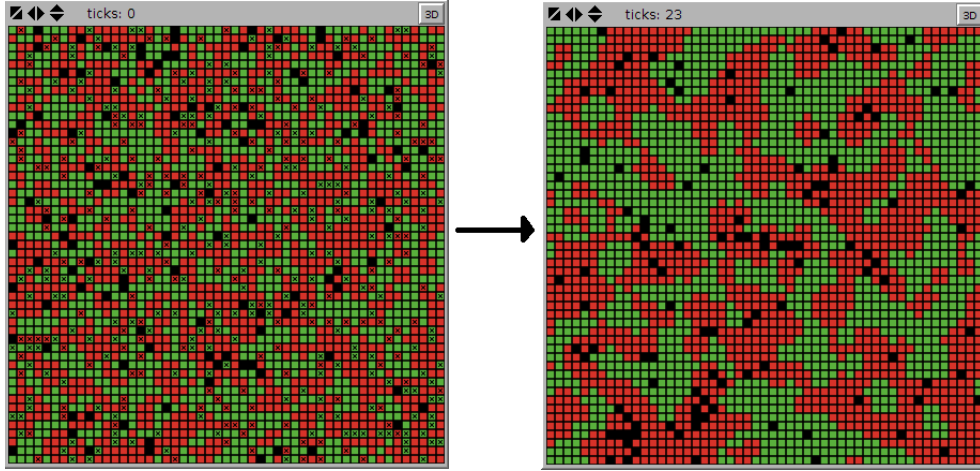


Figure 6.1: Initial and final situations for a 30% tolerance level using an implementation of Schelling’s segregation model in NetLogo library ([Wilensky, 1997](#)). The emergence of clusters is clearly visible.

to interact with some existing structure such as a road, a field, other agents, an organization or have to deal with some kind of external events such as rains or droughts.

There are several definitions of a multi-agent system, of which [ABMs](#) are instances, and I give here the widely-used definition written by [Ferber \(1999, p.11\)](#). “A multi-agent system is a set $\{E, O, A, R, Op\}$ composed of:

- An environment E , that is, a space which generally has a volume.
- A set of objects O . These objects are situated, that is to say, it is possible at a given moment to associate any object with a position in E . These objects are passive, that is, they can be perceived, created, destroyed and modified by the agents
- An assembly of agents A , which are specific objects ($A \subseteq O$) representing the active entities of the system (Section 6.2 provides detailed information about agents).
- An assembly of relations R which link objects (and thus agents) to each another.
- An assembly of operations Op , making it possible for the agents of A to perceive, produce, transform, and manipulate objects from O .
- Operators with the task of representing the application of these operations and the reaction of the world to this attempt at modification, which we shall call the laws of the universe.”

ABMs can be described using this formalism. This definition indicates a suitable paradigm for programming ABM: object-oriented programming. Agents, and more generally objects have specific properties and are related through some relations which recalls the way objects behave in object-oriented programming (Section 6.4).

6.1.2 Advantages and limits of ABMs

As for all methodologies, ABM has some advantages and some limitations that modelers should bear in mind.

6.1.2.1 Advantages

As Bommel (2009) explains, traditionally, mathematical tools have been used to describe and scientifically model the world. However, mathematical models are deemed to be tractable if the modeler wants to make something out of it: either the model considers that all individuals are alike creating a particle-like effect, using an average strategy, or the model considers the distribution of the population along some variables (age, spacial distribution). Furthermore, it is difficult to link the aggregated value of a variable and the value for a single agent, there is no history or trajectory, preventing local tracking. I use this advantage to devolve more time in understanding and modeling diverse scenarios rather than finding mathematically tractable versions of models I design.

In ABMs, there is no limit in following both aggregated and disaggregated values, and in designing ways agents influence and are influenced by the environment. The way an ABM is conceived, using agent-oriented or object-oriented programming (this choice will prove more and more natural along the chapter), makes it relatively easy to design several types of agents making their decisions in different ways, creating and favoring heterogeneity. Herbert Simon (cited in Edmonds and Meyer, 2013a) observed that humans tend to act following a procedural rather than substantive rationality, *i.e.* people follow a predetermined sequence of actions instead of optimizing the sequence or always choosing the best option (see Section 6.4.1.2 for an instantiation of this idea). Thus, people follow heuristics (Tversky and Kahneman, 1974). They tend to change their procedure only if it becomes unsatisfactory. Simon (1982) also developed the concept of bounded rationality according to which people do not have perfect information about their environment, that is fully expressed in how people in models sense and understand their environment in a partial manner. This idea is clearly fundamental in a thesis such as this one since without bounded rationality, information has to be considered known equally by all at all times.

After the design of an ABM, it is also relatively easy to make some changes in the way some behaviors or relations work, without risking of having to end

up with a completely different mathematical model, that becomes at best more difficult and at worse intractable.

6.1.2.2 Limits

ABMs come with some limitations that I take into account as much as possible.

One of the main limitations lies in the difficulty that the modeler has to generalize the outputs of the model. On the one hand, “if one has demonstrated that a certain set of assumptions can result in a set of outcomes, this shows that the modeled process is a *possible* explanation for those outcomes” (Norling et al., 2013, p.43). A model cannot prove something of the form $\forall X, Y$, since X and Y are simplified versions (models) of reality impossible to explore thoroughly. A corollary of this observation is that a model can disprove theorems formulated in these terms. A model can show that $\exists X, \neg Y$. In the case of the model developed in this thesis, I focus on the second part, investigating the question: does more information (X) lead to better resource management (Y)? The goal here is to find some values of X that lead to Y , and some that do not.

Another issue is linked to results linked to programming itself: assumptions made as for the way the system interacts, the internal behavior of agents or the environment reaction. These assumptions can be made explicit for some of them (such as declaring some unknown behavior as a random variable) while others are quite difficult to make explicit (such as those deriving from the modeler personal biases) (Bommel, 2009; Norling et al., 2013). Furthermore, because of the complexity of models, it is often quite difficult for others to replicate them, while it is a part of the scientific verification process (Norling et al., 2013; David, 2013). The question of verification of ABMs is one of the trickiest and covers a wide range of possible strategies that do not yet make consensus but have to be linked to the purpose of the model (David, 2013). A way to deal with this issue is to document in details the simulation to make it easier for other to replicate it. This reason explains the choice of using the ODD (Section 6.4.1.3) protocol proposed by Grimm et al. (2006, 2010, 2013) to describe the model that forces the modeler to answer to a thorough set of questions that leads to revealing as much of the model as possible.

It is important to remember limitations of approaches in order to understand observed results. This point should be applied to all methodologies.

6.2 Agents

Agents are the main entities of ABMs. Models of agents can range from very simple such as in Schelling (1971) segregation model to much more complex ones such as agents endowed with beliefs, desires and intentions (BDI). Ferber (1999, p.9) gives a thorough definition of an agent. He proposes to specify agents in any ABM $\{E, O, A, R, Op\}$ as “a physical or virtual entity which:

- Is capable of acting in an environment E .
- Can communicate directly with other agents in A .
- Is driven by a set of tendencies (in the form of individual objectives or of a satisfaction/survival function which it tries to optimize).
- Possesses resources of its own.
- Is capable of perceiving E to a limited extent.
- Has only a partial representation of this environment (and perhaps none at all).
- Possesses skills and can supply services.
- May be able to reproduce itself.
- Behaves towards satisfying its objectives, taking account of the resources and skills available to it and depending on its perception, its representations and the communications it receives.”

This definition is comprehensive and dictates how we should think an agent in an [ABM](#). Note that actual human being verify this definition.

Usually, two broad types of agents are defined: reactive and cognitive. Reactive agents are supposed to directly respond to their environment or other agents, while cognitive ones formulate goals that they want to follow. Archetypal examples of these types of agents could be an ant (reactive) and a human (cognitive). As usual, the definitions are not that clear and there is a blurred boundary between reactive agents and cognitive agents: these categories should rather be seen as gradient ([Bommel, 2009](#)). Depending on the model, a human agent can be designed as a reactive agent such as in the segregation model. Many choices can be made when designing how agents behave and react. In the model developed in the thesis, there are two main entities: oysters and farmers. Oysters are clearly reactive entities. Farmers agents need to interpret and react to new pieces of information. Thus, they are designed as cognitive agents.

Agents could be all modeled as following the same behavior, but a strength of [ABMs](#) is to be able to develop models in which heterogeneity is included. This characteristic limits the emergence of average behaviors. It usually prevents any analytical solving (which is a drawback compared to other types of mathematical modeling), but regularities and determinism can be observed empirically by performing intensive simulation plans. I used this strength and defined several types of agents who have different goals.

Agents are a very modular concept that is the core of [ABMs](#). Let us now turn to the specific use of [ABM](#) in the context of [NRM](#).

6.3 Agent-based modeling for natural resources management

[SESS](#) are complex systems for at least two reasons. First, there is no single theory or scientific field that explain them. Second, some characteristics such as social norms seem to emerge from individual behavior and interactions between individuals. [ABMs](#) are particularly adapted tools for their study since they provide a transdisciplinary paradigm and allow to specify micromotives and observe resulting macrobehaviors ([Bousquet and Le Page, 2004](#); [Janssen and Ostrom, 2006](#); [An, 2012](#); [Le Page et al., 2013](#)). It has been applied to all kinds of resources in a wide variety of contexts. In a review, [Le Page et al. \(2013\)](#) give a number of references for applications in subjects as diverse as: land-use dynamics ([Ralha et al., 2013](#)), water management ([Barreteau et al., 2004](#)), forestry ([Purnomo and Guizol, 2006](#)), or wildlife ([Anwar et al., 2007](#)).

As [Bousquet and Le Page \(2004, p.314\)](#) put it in their review of [ABM](#) for ecosystem management:

Scientists working in [the area of ecosystem management] need to examine the interactions between ecological dynamics and social dynamics. Indeed, for many years, this question was examined either exclusively from the angle of “an ecological system subject to anthropogenic disturbance” or, from the angle of “a social system subject to natural constraints”. [...] For [20] years now, the challenge has been to develop a new approach focusing more on the interactions between ecological and social components and taking into account the heterogeneity of these components.

[ABM](#) is a suitable methodological answer to the requirement of switching from a system constrained by another to systems in interactions. This perspective in a [SES](#) context allows, if not forces, a double investigation as much on the ecosystem side as on the social side. There is no specific reason for making ecology dominant over society, or society dominant over ecology. The actual world around us is working in interaction, ecology and society shaping, affecting, constraining and offering opportunities to each other.

6.4 The technical side of the ABM

Multiple tools exist to design, implement and describe [ABMs](#). Some tools are used to program, others to explain or specify. In the following section, I introduce the description tools, [UML](#) class, sequence and activity diagrams and the [ODD](#) protocol that I used to specify the model as well as the program, [CORMAS](#), that I used implement the simulation.

6.4.1 Description tools

The object-oriented programming paradigm is well adapted for multi-agent modeling and simulation. This paradigm encourages the creation of *classes* (an instance of which is called an *object*) that have specific *attributes* (variables with fixed or mobile values) and *methods* (actions the object can perform). These different classes can interact in specific and precise ways defined by the programmer. In the case of ABM, this paradigm is relevant since the objective is to design agents that behave according to some sequences of rules and interact with other agents or with their environment.

Note that some ABM meta-models are based on specific agent-oriented programming languages (*e.g.* NetLogo, Gama) that are “specialization of object-oriented programming. The state of an agent consists of components such as beliefs, decisions, capabilities, and obligations” (Shoham, 1993, p.51). However, using object-oriented languages is convenient since we can use the vast knowledge and practices developed in this field, particularly code organization and description.

Indeed, programming in such languages requires planning. The tools described in the rest of the section are useful for that purpose. They have the other advantage of making communication about the structure of the model and discussion easier.

In the rest of the section, I introduce classical notational languages that I will use to describe the ABM of the thesis: UML for class diagrams, sequence and activity diagrams and the ODD protocol. This section only covers the basic techniques that I used in the thesis, these languages have many other specificities.

6.4.1.1 UML - Class diagrams

Unified Modeling Language (UML) is a notational language that was intended as “a standard means of expressing design that would not only reflect the best practices of industry, but would also help demystify the process of software system modeling” (Fowler, 2004). Since there are several notations in the language, I will precise the meaning of the symbols that are used in the thesis.

The first type of diagram used to describe models is the class diagram. Figure 6.2 shows examples of classes taken from an ABM developed in Bommel et al. (2012). All diagrams are drawn using the UMLet¹ open source program. Boxes are divided into three part. The upper part contains the name of the class, in italic if abstract. The middle part contains attributes and the bottom part, methods. Figure 6.3 shows a class diagram that focuses on interactions. A simple line is an *association* (a *Forager* daughter class instance is associated with exactly one instance of *Plant*); a diamond is an *aggregation* (a *Landscape*

¹<http://www.umlet.com/>

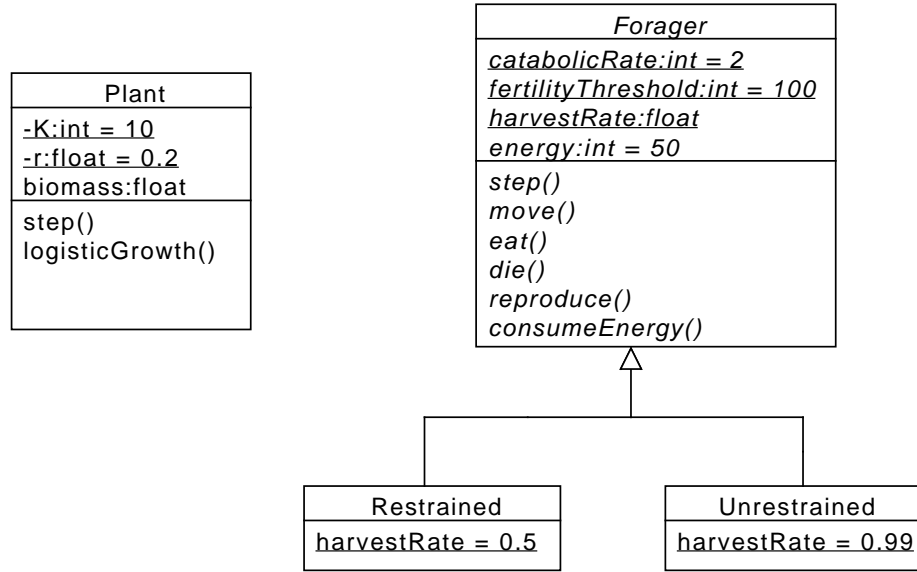


Figure 6.2: Example of simple and abstract classes with inheritance (Bommel et al., 2012).

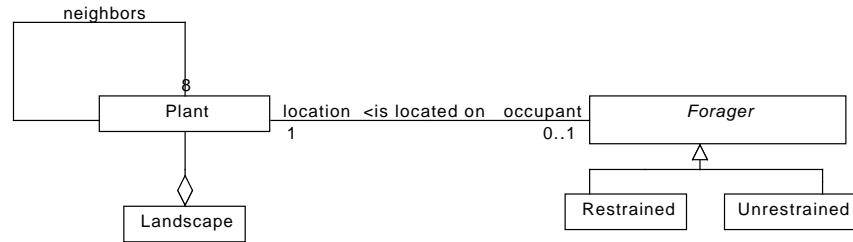


Figure 6.3: Example of interactions in a class diagram (Bommel et al., 2012).

instance is an aggregation of **Plant** instances); and a white triangle symbolizes inheritance (**Restrained** inherits from **Forager**).

6.4.1.2 UML - Sequence and activity diagram

A sequence diagram is a diagram that describes sequential procedures that objects follow. This type of diagram is a technical implementation of Herbert Simon's idea of the fact that humans behave in a procedural rather than a substantive way. The most important sequence diagrams in the case of ABMs describe the main *step* method which is an organization of the objects sequence

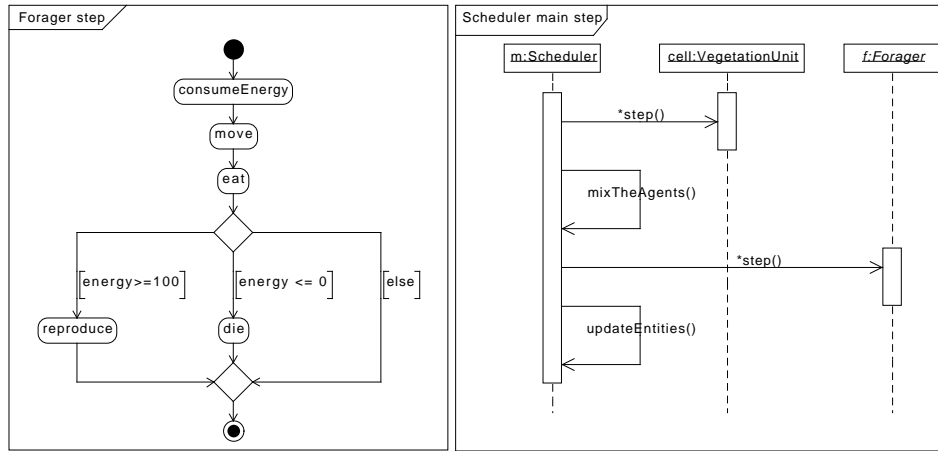


Figure 6.4: Example of activity and sequence diagrams (Bommel et al., 2012).

of behavior. The right side of Figure 6.4 shows an example of such a diagram in the same model as in section 6.4.1.1. These diagrams are simple to read. The entities designed in the top box performs the listed methods from top to bottom.

An activity diagram is type of diagram used to described complicated methods (Fowler, 2004), such as step methods. The left side of Figure 6.4 shows an example of the step activity diagram of the forager described in Figure 6.2.

6.4.1.3 ODD(+D) protocol

The **Overview, Design concepts, and Details (ODD)** protocol was proposed as a standard protocol for describing **ABMs** in scientific papers (Grimm et al., 2006, 2010, 2013). It was developed initially in ecology by 28 researchers as a response to the lack of precise description framework for simulations and has been globally welcomed in the community with at least 50 models using the protocol 4 years later (Grimm et al., 2010). Even though it is possible to apply directly the protocol to describe **ABMs** in the context of **SESSs**, there has been a refinement of the protocol specifically for the study of **SESSs** or more generally when human decision is modeled in some way. Müller et al. (2013) propose the **ODD+D** (for decision) protocol that extends the classic **ODD**. Table 6.1 shows the different elements proposed in the **ODD+D** protocol to describe the **ABM** one has developed, or is currently developing. Each one of these themes is designed to answer a set of questions (listed in Table A.1, p.256) that I follow to describe the model.

The **UML** diagrams that have been detailed in the previous sections only answers to parts of “entities, state variables and scales”, as well as the “process overview and scheduling”, a tiny fraction of the global description of a model.

Table 6.1: The ODD+D protocol (Adapted from [Grimm et al., 2013](#); [Müller et al., 2013](#)). Table A.1, p.256, lists questions associated with each structural element.

Main block	Structural element
Overview	Purpose Entities, state variables and scale Process overview and scheduling
Design concepts	Theoretical and empirical background Individual decision-making Learning Individual sensing Individual prediction Interaction Collectives Heterogeneity Stochasticity Observation
Details	Implementation details Initialization Input data Submodels

6.4.2 Simulation and analysis tools

This section completes the “implementation details” section of the ODD. Numerous platforms exist to program a ABM, see [Nikolai and Madey \(2009\)](#) for a comparative review. Platforms can be very generic or more specific; focus on communication or on agent decision-making processes; provide visualizations or not. They are implemented in all kinds of programming languages and can be created from scratch by users. Already implemented programs have the advantage to help users in creating the simulation.

6.4.2.1 CORMAS

In the case of the thesis, the focus is on agents interacting around a natural resource that they wish to use and understand. Given the ecology of platforms that exist, I turned to a platform called CORMAS², Common-Pool Resources and Multi-Agent Systems ([Bousquet et al., 1998](#); [Le Page et al., 2012](#)). This platform comes with two important advantages: first, as the name suggests, it

²<http://cormas.cirad.fr/indexeng.htm>

is oriented towards [NRM](#) and second, it is widely used in the laboratories I am affiliated with. CORMAS is based on the smallTalk language (a pure object-oriented language) and uses a visualWorks implementation which is moving towards an open-source version on Pharo³. I used version 2014.5.14 adapted for Ubuntu 12.04.

The basic principles of CORMAS is that there is an environment that consists of an aggregation of cells. These cells are considered the basic spatial entities (a field, water ...). The second element is the agents. These agents can be located and/or social. Choosing a specific version of an agent enables the use of different methods that are implemented. For instance, if agents are social, they can have a network and exchange messages with other agents, if they are located, they can move. Third, one can create passive objects that can be manipulated by agents or the cells.

6.4.2.2 R

R is a statistics open-source software ([R Core Team, 2015](#)) that is widely used in the statistics and data analysis community. It provides numerous packages that are useful to analyze data. I used R version 3.2.2, and Rstudio version 0.98.1102 [RStudio Team \(2012\)](#), an integrated development environment for R. I also intensely used some packages for the analysis of the [ABM](#) such as dplyr to manipulate data ([Wickham and Francois, 2015](#)), tidyr to clean data ([Wickham, 2014](#)) and ggplot2 to draw graphs ([Wickham, 2009](#)). I am thus grateful to Hadley Wickham for implementing a precise and specific grammar of graphics ([Wilkinson, 2006](#)) and precise and easy to use verbs dedicated to specific uses in data analysis. I strongly suggest to the reader who needs to analyze data to investigate these packages.

6.4.2.3 R-CORMAS

In an [ABM](#), there are multiple attributes that the modeler can change. Exploring values enables the modeler to understand the model or draw conclusions about the phenomenon he/she is trying to unveil. CORMAS possesses internal tools that allow to explore the space of parameters.

However, these tools are quite static (move around a value or divide a range into equally distanced values) and do not allow easy handling of replications while they are necessary to gum out stochasticity. To overcome these limitations and inspired by the link that was created between R and Netlogo another [ABM](#) platform ([Thiele and Grimm, 2010](#)), we decided (with Dr. Bruno Bonté) to develop a link between R and Cormas. R role is to create a matrix of n lines and p columns, where each line is a scenario containing the p values for the variables that the modeler intends to explore. The role of CORMAS is then to read the values sent by R and execute the simulation.

³<https://github.com/cormas/cormas>

6.5 Conclusion

In this chapter, I described [ABMs](#) as a widely used tool that helps to understand complexity, linking micromotivations and macrobehaviors. [ABMs](#) are composed of three main elements: the agents, the environment and their interactions. They have advantages such as describing the world in terms of sequence rather than tractable mathematical formulas and are quite flexible. However, they are difficult to replicate and verify. Despite these limitations, they are a useful tool that I use in the rest of the thesis. After having described agents in details, I focused on the use of [ABMs](#) in the context of [NRM](#). In this domain, it is considered as a tool that is increasingly important, as much for prediction than understanding or participation. After having discussed these theoretical points, I went into the detail with some technical tools that are useful for creating and communicating [ABMs](#). The [UML](#) paradigm and their diagrams (class, sequence and activity) are used to describe technical parts of the implementation either globally or locally. The [ODD](#) protocol is used to communicate thoroughly a model in ecology and the ODD+D protocol is specifically dedicated to communicate on models that include human decision making. Finally, I described the implementation details of the model: the use of the CORMAS platform coupled with the R statistics software.

Part III

Case Studies



Case studies - Introduction

The following chapters contain the contextual part of the thesis to which I apply the concepts introduced in Part I. The two case studies are focused on oyster farmers, their relation with their environment and their role as actors of a [Social-Ecological System \(SES\)](#).

As a first step, in Chapter 7, as advised by [Edwards and Steins \(1999\)](#), I frame the general context in which oyster farmers act, that is in estuaries, mouths of coastal catchments, highly diverse environments both ecologically and for human usage. I use the [SES](#) framework to unite cases and see beyond specific elements of cases, going into oyster farming through the ecology of oyster farmers environment (estuaries and catchments), the biology of oysters and techniques to farm oysters. This case provides an opportunity to discuss the linked questions of scales and boundaries of [SESs](#).

Then, in Chapter 8, I describe, drawing on the [SES](#) framework, the specific two cases that I investigated in detail using the methods described in Chapter 5: Thau Lagoon, France and several estuaries in [New South Wales \(NSW\)](#), Australia. In the description, in addition to the historic, economic, social and political elements, I focus particularly on information sharing artifacts that actors (oyster farmers or public authorities) have developed to cope with threats. The use of the [SES](#) framework allows for a broad comparison of cases which is presented at the end of Chapter 8. This comparison points out variables that are significantly different in the cases studied: size and community.

To conclude, in Chapter 9, I present oyster farming through the lense of threats, pointing particularly two threats: the microbiological one, a public threat; and the virus one, private. In this chapter, I show that the concepts developed and presented in Chapter 3 allow an easy framing of oyster farmers situation.

Chapter 7

Estuaries, Oysters and Oyster Farming

Oyster farming occurs in the brackish water of estuaries. Estuaries surroundings have been inhabited and used by man for thousands of years (Day et al., 2013c). Their importance to man of and the influence of man on estuaries are recognized (Day et al., 2013b).

The case studies of this thesis are focusing on oyster farming, and thus on estuaries. This case is relevant for several reasons: oyster farmers act in a fundamentally open system difficult to study with the traditional goods framework (Table 2.1, p.13) and are subject to threats (Chapter 9).

Studying these cases with the lense of the SES framework encourages the analyst to describe system actors evolve in using a multidisciplinary perspective. As much as humans shape the environment they live in, the environment shapes humans and their institutions. Someone trying to understand institutions, rules, behaviors and norms of humans acting around a resource should not overlook a description of their environment. In this chapter, I focus mostly on the resource system actors use, the resource units they produce and how they produce them, *i.e.* the ecological side of the SES. Such a contextual focus is supported by Edwards and Steins (1999) who insist on the importance of describing precisely the environment and interactions in a multidisciplinary perspective.

First, I give a brief overview of the ecology of estuaries and catchment basins to provide the reader a broad view of the system background. Then, I focus on oysters and their important ecological functions, showing that they can be considered bioindicator species. After that, I describe practices of oyster farmers. Finally, I discuss choices that have to be made to describe a SES and their implications for the analysis (Table 7.2).

This chapter is intended to be as general as possible, drawing on the knowledge acquired through literature and interviews, to give a general view that can go beyond the specific cases I had the opportunity to investigate in-depth.

7.1 Catchments and estuaries

Catchments and estuaries can be considered nested systems, as shown in Figure 7.1. The turquoise and blue nested squares show possible limits of the system. These limits are the result of a modeling choice. The difference lies in considering some flows as internal or external and depicts representations of the modeler, or of actors within the system. This modeling choice has important outcomes, as I will show in Section 7.4 and in Chapter 10.

Figure 7.1 shows catchment basin and estuary as two different reservoirs even though this choice could be questioned in the point of view of hydrology (the estuary is part of the catchment). However, since we are mostly focusing on actors' points of view, it can be argued that for someone working mostly on the estuary, the catchment can be seen as external and simply providing an inflow of water. The nested part of the system is represented by the background rectangles.

Whatever the choice, it is necessary to understand the basics of estuarine ecology. First, I describe estuaries and some of their important characteristics. Second, I take a step backward to briefly describe catchment basins, and then link the two through water quality issues.

7.1.1 Estuaries

The commonly used definition of an estuary is: “a semi-enclosed body of water that has free connection with the open ocean and within which sea water is measurably diluted with fresh water derived from land drainage” (Pritchard, 1967; Dunster, 2011; Day et al., 2013c). This situation makes estuaries water brackish. “There is a continuum of estuarine types. At one end of the spectrum exist lagoons (...), at the opposite end of the spectrum lie deltas. (...) Between lagoons and deltas lie estuarine lagoons, estuaries, estuarine deltas, representing a mixture and gradation of the two extreme coastal environments” (Snedden et al., 2012, p.20). Differences are shown in Figure 7.2. The reader can notice that this representation does not include the rest of the catchment basin.

Lagoons and estuaries have close properties and in the case of this thesis, there is no need for further distinction, since they will here lead to same types of management, use, face similar threats and belong to close SESs. When citing the names of real places, I will use the vernacular one (with the apposition of estuary, river, inlet, or lagoon when appropriate), and I will use solely estuary as a generic term when referring to this type of ecosystem. This is the way they are referred to in the reference book *Estuarine Ecology* (Day et al., 2013a).

Estuarine ecosystems are composed of several ecosystems that form a complex system. Estuarine environments are challenging to live in due to important salinity and turbidity changes, mostly due to tides. Despite this element

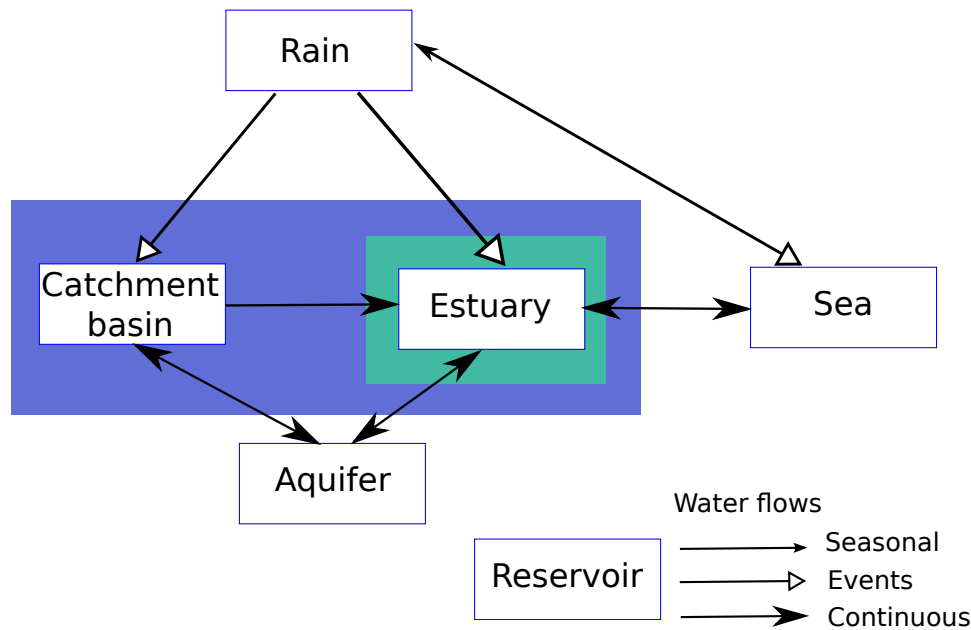


Figure 7.1: Coastal water flows: catchment or estuary?

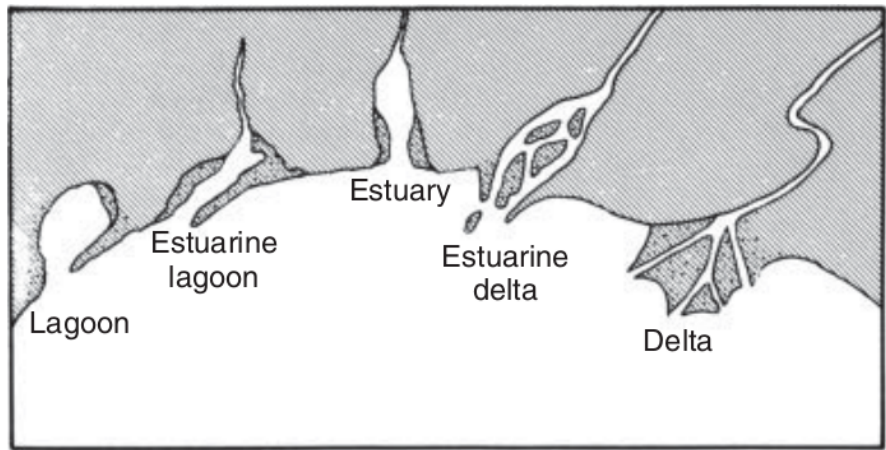


Figure 7.2: Schematic representation of the continuum of inlet types from lagoons to deltas (Snedden et al., 2012).

(or thanks to), they are recognized as high productivity ecosystems (Day et al., 2013c).

7.1.2 Catchments

Catchment basins are defined as the total area draining into a given reservoir or impoundment area (Dunster, 2011). Water coming from all points of the catchment exit in a point where it converges. Estuaries or lakes are typical exit points. Activities that have a link with water such as farming or cities (use and treatment of water) have consequences on the exit point of a catchment.

Estuaries are open systems. Actually, they can be considered as an interface between the catchment basin and the sea or the ocean. A catchment basin is a more closed system than an estuary since water can enter this system only through rain or from underground reservoirs and to a little extent at the end point (Figure 7.1).

7.1.3 Water quality

Water has characteristics that can be measured (chemical, physical, biological). Water quality is the measure of all these elements in relation with something (*e.g.* capacity of humans to use it, of animals to live in it).

Water quality in estuaries is influenced by activities on estuaries, and by flows of water entering the estuary. Figure 7.1 shows water exchanges of estuaries with other systems. Changes of water quality can come from within (internal pollution), from the rest of the catchment, and from the sea (and thus other catchments).

“Coastal primary production and phytoplankton biomass are strongly controlled by the availability and supply rates of nutrients, especially nitrogen and to a lesser extend phosphorous” (Paerl and Justic, 2013, p.98). There is a substantial effect of human activities on water quality.

Agricultural fertilizer run-off coming from catchments has important consequences on ecosystems such as eutrophication due to increases in nitrogen and phosphorous (Schindler and Vallentyne, 2008). This massive inflow of nutrients has an impact on estuarine phytoplankton. Phytoplankton can proliferate in explosive ways due to fast growing rates in the order of one doubling per day (Paerl and Justic, 2013). When there is a high inflow of fertilizers, their growing rate can create algal blooms which affect negatively water quality. These algae use all the available oxygen in the water and create hypoxic or anoxic conditions which are difficult to handle for other species. In the end, the whole trophic web can be touched in dramatic ways. At worse, this overflow of nutrients can create dead zones such as in the Gulf of Mexico, or less dramatically, limit the environmental carrying capacity of estuaries (Rabalais et al., 2002).

Water in estuaries¹ and water quality are non-excludable and non-rivalrous. Thus, they are public goods (Table 2.1, p.13). Water quality may be measured through a wide variety of water quality indicators (Fairweather, 1999). For instance, in Australia, water quality indicators are developed on five estuarine-related components: aquatic ecosystem health; primary (swimming) and secondary (boating, fishing) contact recreation; visual amenities; and aquatic commercial food production (NSWDEC, 2005). Each of these components is related to a set of variables. A variety of indicators are defined to measure water quality. For instance, short term impact of human activities in the estuary is measured through the level of *Escherichia coli* (*E. coli*) which can lead to health troubles (from diarrhea to death). *E. coli* levels are measured in cfu/100 mL, *i.e.* colony forming units, an estimation of the number of viable bacteria cells in a sample of 100 mL. For aquatic ecosystem health, the main indicators are (harmful) algae blooms and the level of nutrients in the water for the reasons stated above. More indicators can be found in NSWDEC (2005) and in Table 8.1, p.120, which is dedicated to indicators related to oyster farming.

Water quality in estuaries is strongly linked to catchment activities. Even though water quality can be measured anywhere, since estuaries are exit points of catchments, water quality in estuaries can be thought as a possible indicator for sustainability of activities in the catchment, at least as far as water flowing is concerned. If water quality affects species which are linked through a dense relation web working at several levels (physical, chemical, biological), it also affects people who use estuaries professionally or for leisure.

7.1.4 Users of estuaries

The interaction between humans and estuaries is old. This interaction is due to the high productivity of estuaries (mostly fish and shellfish) and to their positions at the border of river mouths and the sea that provides an ideal location for trade (Day et al., 2013b). In this section, I will first evoke direct users of estuaries and second, indirect users.

Estuaries are used directly by some categories of actors. I will order the uses in terms of water quality requirements seen as a possible usage for humans. Thus, I use *E. coli* increasing limit levels for this classification. I chose to use the Australian levels but French levels are relatively similar. SAGE-Thau (2015, pp.141-143) provides information about French legal levels.

Users that need the best water quality are oyster farmers (or shellfish growers more generally). It is forbidden to harvest and sell oysters when *E. coli* are more than 14 cfu/100 mL. The second most demanding activity is primary usage (swimming) which is forbidden when *E. coli* levels are higher than 150 cfu/100 mL. The last one is secondary usage (fishing) that is forbidden

¹I consider here water as an environmental element. Water going to estuaries may be pumped for diverse activities and is thus rival.

when levels are higher than 1000 cfu/100 mL (NSWDEC, 2005). These figures show clearly that if the water is of a good enough quality to ensure selling of shellfish, then its quality is good enough for all other usages. Shellfish farmers are those who are the most impacted by variations in water quality. Shellfish growers, fishermen, swimmers, surfers and other leisure users are the main direct users of estuaries, in the sense that they are those who are in direct contact with water. Another type of usage that is independent from water quality is trade. Trade boats use the water of estuaries as a link between the sea and the hinterland. Many of the big cities in the world are located near estuaries (*e.g.* New York, Sydney, Cairo, Dacca, Sao Paolo) and contain harbors that are used for trade (Day et al., 2013b). Apart from these major examples, estuaries are often surrounded by cities.

The evocation of cities lead to unveil other kinds of less direct links between humans and estuaries. Cities extract water from some source and reject, usually after treatment, water that can end up in estuaries. In this sense, all inhabitants of coastal catchments with an estuary as exit point can be considered as users of estuaries. The other actors that have an impact on estuaries are farmers as discussed in Section 7.1.3, mostly by spreading fertilizers that run-off in the water, by extracting water for irrigation or through cattle chewing coastal natural systems such as mangroves and producing manure that end up in the estuary (Gietzelt et al., 2014).

Those different types of users lead to diverse interconnected effects, positive or negative. Figure 7.3, adapted from Mongruel et al. (2013), shows some of these using effects of microbiology variations. For instance, cities effluents and agricultural fertilizers can increase microbiological density in the water and provide important amounts of primary food that fuels estuarine food webs. Tourist use of estuaries is correlated with an increase of pressure on leisure uses: an increasing demand of marinas, space for boating or surfing as well as fresh fish and shellfishes. These two examples show that a compromise needs to be found between these uses. To reveal this need for balance, a complex vision, intertwining climate, chemistry, biology, infrastructures, policies, the economy such as the one provided in Figure 7.3 or the SES framework is required.

7.1.5 Catchment and estuaries in short

Estuaries and catchments are related systems: estuaries are nested in a catchment area. Estuaries have long been used by humans and are highly productive systems. Some of these uses require high levels of water quality (in terms of levels of some elements in the water for a specific use), other uses are linked in an indirect manner. Aquaculture is the most demanding activity on estuaries regarding water quality. This is a reason for choosing this activity as an emblematic usage of estuaries. Thus, we need now to dig deeper into oyster farming. But to understand oyster farming, we first need to understand oysters.

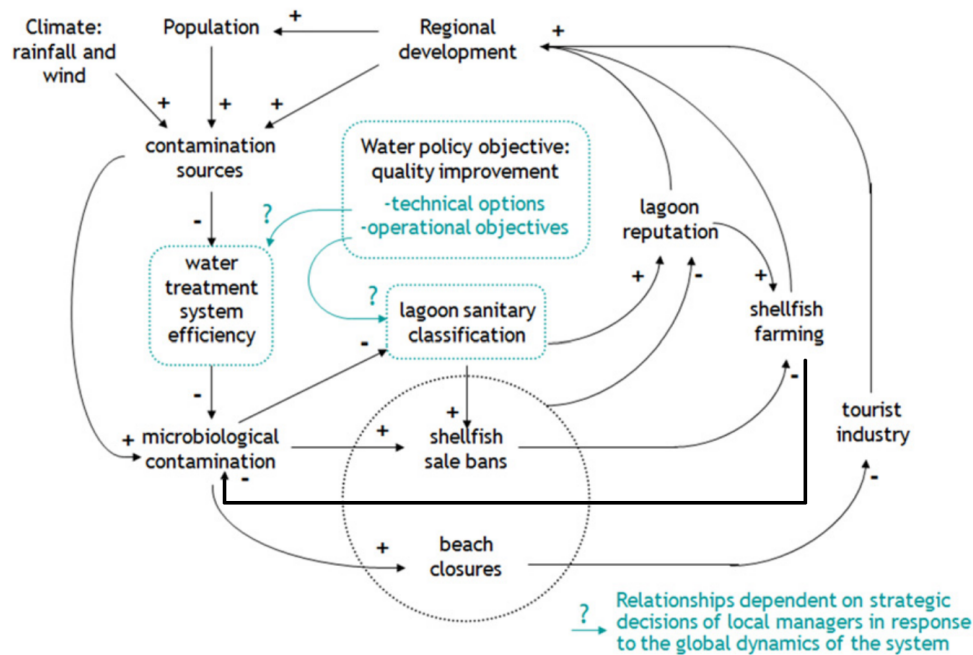


Figure 7.3: Some of the influences in microbiological levels variations. I added a feedback from shellfish farming to microbiological contamination since oysters filter microbiological for food (Adapted from Mongruel et al., 2013).

7.2 Oysters

Humans extract two main types of food from estuaries: shellfish and fish (nekton). These species belong to a complex food web that was evoked in Section 7.1. Their abundance depend on other elements that are influenced by climate and by human activities. Oysters, and more generally, molluscas can be considered as bioindicator species.

7.2.1 Biology of oysters

Oysters are part of the benthic fauna and have been consumed by humans for millenniums (Wilson and Fleeger, 2014). Oysters are tolerant to salinity variations and can survive and grow in water containing from 5 to 42 practical salinity units (1 psu is 1 g of salt per kg of water and sea water is at 34 psu on average). They are located in the tide range of the estuary, on an oyster reef, or bed. They are a suspensivore species, or filter feeders, which means that they extract their food from the material suspended in the water column, including phytoplankton and zooplankton, as well as any other material in suspension (Wilson and Fleeger, 2014). This food can be considered a **Common-pool resource (CPR)** to oyster farmers since it is non excludable and subtractable.

Table 7.1: Oysters as resource units. I removed RU4 - Economic value since it depends on location.

† These variables are those proposed in Table 3.6, p.40.

Code	Variable	Value
RU1	Resource Units Mobility	None - Except with handling
RU2	Growth or replacement rate	Pacific oysters - 2 years for triploids, 3 to 4 years for diploids
RU3	Interaction among RU	No direct interaction, share phytoplankton
RU5	Number of units	Millions
RU6	Distinctive characteristics	None - Located on private leases, thus easily recognizable
RU7	Spatial and temporal distribution	Fixed (cf. RU1) - On private leases
RU8 - Threats to resource units† (Chapter 9)		
RU8a†	Biological	Microbiology, algal blooms, virus, sea bream
RU8b†	Human-related	Microbiological peaks (tourism, cities)

Oysters can live for several decades. Males release sperm and females eggs into water. Eggs are fertilized and produce spat that are moved by currents before they land on an oyster bed to fix on for the rest of their monotonous lives that they spend under the rhythm of the tides, filtering water. Table 7.1 gives the Resource Units variables for oysters using variables proposed in Table 3.6, p.40. These variables are similar for oyster farming around the world.

7.2.2 Ecology of oysters

Oysters have been recognized as having a positive influence on estuarine ecosystems (Newell, 2004; Shumway, 2011). As a filter feeder species, they extract particles from the water column, limiting turbidity and providing space for important benthic plants such as seagrasses. Oysters filter an estimated 0.5 to 1 ML of estuarine water during their lives, removing phytoplankton and other suspended material (White, 2001).

In *Shellfish aquaculture and the environment* (Shumway, 2011), the authors explore several positive effects of oyster farming and aquaculture on the environment. “Most shellfish aquaculture is thought to have an overall positive effect on water quality, primary production, and biodiversity, except, as mentioned, for intensive culture in localized, poorly flushed waters” (Shumway, 2011, pp.195-196). Specifically, shellfish can be added in eutrophied estuaries to be used as filters, allowing for instance light to reach deeper waters.

7.2.3 Oysters as bioindicators

When actors try to evaluate the environmental efficiency of some policies, or rules, or infrastructures, they face an issue due to the complexity of topics such as conservation of ecological diversity. A recurrent strategy is to define indicator species, “a subset of attributes that could serve as surrogates for total biodiversity and be used as indicators to monitor the success or failure of management practices to sustain biodiversity” (Lindenmayer et al., 2000, p.942). There are several types of bioindicators that need to be carefully chosen. The typology that I use in this Section is exposed in Lindenmayer et al. (2000). In the light of complexity, the idea of erecting a single species as indicator for all biodiversity seems dubious (Lindenmayer et al. (2000) discuss this idea focusing on failures), as much as projecting all human behavior on the single scale of money (or the more esoteric notion of utility). Some authors tried to go beyond selecting a single species by using a list of species (that comes with more difficulties) or by involving complexity using structure-based biodiversity indicators. However, this strategy can be useful in some cases. For instance, the presence of a specific type of plant is an indicator (a proxy) of some kind of soil, or the presence of some types of nutrients or pollutants *e.g.* the presence of an algal bloom reveals a high inflow of nutrients (type 5 indicator).

Oysters have long been known to accumulate metals and have been used as an indicator for metal concentrations in estuaries in Hong-Kong Waters (Phillips and Yim, 1981) or in the Gulf of Mexico (Rosas et al., 1983). In this case, they are type 3 indicators: a species whose presence indicates human-created abiotic conditions such as air or water pollution (Lindenmayer et al., 2000). Oysters have been shown to be efficient type 5 bioindicators of nitrogen sources (Fertig et al., 2010) or to isolate poultry farming impacts (Fertig et al., 2014) and even as a multi-bioindicator in a study where a local oyster was “selected to evaluate the health status of three estuarine areas impacted by anthropogenic activities along the Brazilian coast” (Valdez Domingos et al., 2007, p.350). In the introduction of this study, the reader can find several examples of the use of bivalves (including oysters) as biomonitors for contaminants or toxins for instance. In a study for the Australian public authorities dedicated to the safeguarding of environment conditions for oyster cultivation, White (2001, p.14) suggests oysters as a bioindicator of estuarine good health, a means to support the industry. Type 3 and 5 (among others) are proposed as indicators of abiotic conditions and/or changes in ecological processes.

Thus, oysters have a major effect on estuarine ecology, by filtering water or limiting turbidity and have been shown to be a useful bioindicator species, alongside with other types of bivalves. Now let us turn to the relation between oysters and humans, through oyster farming.

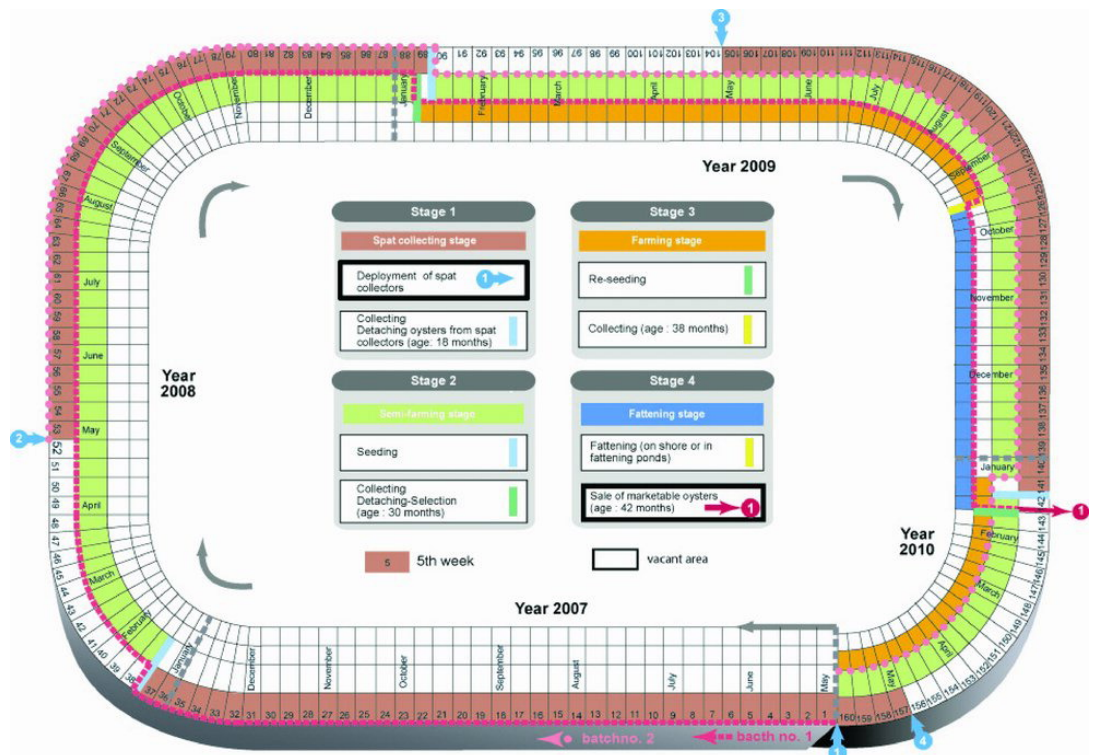


Figure 7.4: Archetypal overview of the breeding cycle of *Crassostrea gigas* in the Bay of Bourgneuf, France (Tissot et al., 2012). Growing speed vary with estuaries and figures should be taken with care.

7.3 Oyster farming

7.3.1 Practices

Here, I describe briefly the general process that farmers have adopted to grow oysters. This process is explained in more detail by going through different growing techniques used around the world in FAO (2001). Tissot et al. (2012) represented a whole breeding cycle of Pacific Oyster *Crassostrea Gigas* (PO) in the Bay of Bourgneuf, France (Figure 7.4). In this section, I will refer to the stages of this figure.

Oyster farmers have several techniques to produce oysters. To find spat (the spat collecting stage), they can use natural catchment or buy them in hatcheries if available. Hatcheries provide several forms of oysters, mostly the PO, which represented 97.4% of world production of oysters in 2005², available under two types: the sterile triploid (which can only be obtained

²<http://en.aquaculture.ifremer.fr/World-statistics/Molluscan-Shellfish-farming/Production-per-family/Ostreidae>

from hatcheries (Guo et al., 1996)) and the diploid (the natural ploidy of oysters).

Once bought or caught, the semi-farming stage starts. The spat is put in growing baskets, racks, bags, or other types of material for them to grow. At this stage, oysters have grown and need to be replaced in other types of baskets or suspended on chords and attached with concrete until they big enough. At that point, they go through the fattening stage. The growth length is described for the diploid PO. Triploids grow faster than diploids since they do not need energy for reproduction (Guo et al., 1996). The months figures are given as an approximation. Different estuaries have different nutrient loads and nutrients availability affect oyster growth (see model in Gangnery et al., 2003). It is common for oyster farmers to be specialized in a specific stage of the growth, benefiting from the appropriate conditions of the estuary they have their leases in. These oysters are moved according to properties of estuaries to optimize their growth. They carry along water, bacteria, and viruses. They are sometimes called “highway oysters” (interview with oyster farmer, November 2014).

7.3.2 On the difficulties to farm oysters

Oyster farming is an activity similar to farming in the sense that farmers grow oysters that are placed on a table, grow and are harvested to be sold. Instead of farming a plot of land, oyster growers use a plot of water (the first few meters under water) to grow oysters. However, land-based farming takes place in a land that can be enriched (using fertilizers) and from which pests and other types of threats can (sometimes) be managed using pesticides or fungicides, with consequences for the soil and for the surroundings (such as soil death, water pollution, or algal blooms). These solutions, even though at the origin of externalities, enable a farmer to cope with threats linked to the crop the farmer wants to grow: for these issues, farmers can exclude themselves from the threat, whether it is internal or not.

Even though there are effects of growing techniques (Girard et al., 2010), oysters growers mostly depend on local estuarine and catchment ecology, with their associated practices for farming or for water treatment (Mongruel et al., 2013). Options available to land farmers are (almost) not available to an oyster farmer. This unavailability provides substantial sparings in inputs, but it makes oyster farmers quite helpless when issues arise. There would be no point in trying to feed one’s oysters since food would be taken away by the water flow. Sea bream eat baby oysters (in the Thau Lagoon), but oyster farmers cannot use pesticides to deal with this threat (though they can ally with fishermen). Collective solutions are required to deal with those threats which are generally not excludable.

Table 7.2: Estuary or catchment? Consequences on the analysis of the SES for a selection of variables.

† Since the situation is here abstract, I indicate categories of actors instead of a number.

Variable (Table B.1)	Estuarine level	Catchment level
RS1 - Sector	Oyster farming, fishing, leisure	Same + Cities, farmers
RS2 - Clarity of system boundaries	Clear but important in and out flows (Figure 7.1)	Clear from the point of view of hydrology, does not necessarily fit with political organization
RS3 - Size of resource system	Size of the estuary	Size of the catchment (larger)
RS4 - Human constructed facilities	Oyster leases and sheds, harbors, coastal housing	Same + Cities, farms ...
RS5 - Productivity of system	Oysters, fish, amenities	Same + agricultural products
A1 - (Number of)† relevant actors	Oyster farmers, fishermen	Same + farmers, water management authorities
A8 - Importance of resource (water)	Fundamental	Important
ECO2 - Pollution patterns	Most pollution comes from catchment	Mostly internal
ECO3 - Flows into and out of focal SES	Water flows come from catchment and sea	Mostly internal with exchanges with sea

7.4 The SES as a choice

When one describes a [SES](#), one needs to define the boundaries of the resource system. As explained in Chapter 5, in the cases that I am studying in this thesis, I use oyster farming as a key profession and the way information sharing can help to deal with threats linked to oyster farming and more generally water.

While studying oyster farming, it could be tempting to limit the scope of the resource system to estuaries, where oyster farming actually occurs (if we exclude buying spat, moving oysters between estuaries and selling in markets). This would be a relevant choice and would limit the geographical areas to the one used by oyster growers. It depends on the question that we are trying to address. If we are focusing on a virus that affects only oysters, then this choice makes sense (Chapter 9).

However, if this choice is made, important flows would be external and difficult to integrate in the analysis: water flows (Figure 7.1), microbiological flows (Figure 7.3), or nutrients flows (Section 7.1.3) among others. Taking

into account the importance of these flows, be them assets for oyster growth (nutrients) or threats (microbiology) for human consumption, prompt the analyst to enlarge the scope of the SES to catchment basins. Table 7.2 gives consequences for the analysis on a selection of SES variables.

This distinction is important for the analyst and probably even more for actors. If an oyster farmer limits his views solely on the estuary, then it would be quite difficult for the farmer to consider ways to deal with threats that (s)he has to face (Chapter 9). The actors would be stuck in a downstream situation (Figure 7.1 shows this upstream (catchment minus estuary) downstream (estuary) situation), where the upstream actors provoke strong physical influence and not much can be done (Section 2.2).

Choosing catchments is of course more inclusive and allows a larger view of the situation. However this comes with limits as well. When trying to grasp catchments as a hole, one has to struggle to know what to include, what not to include. When one chooses to consider a whole catchment as a SES, other choices open up. For instance, should relevant actors (A1) include the whole population of the catchment as well as tourists since they have an influence on water and on the local economy, for instance by eating oysters? Should they only be limited to those that have a specific impact (including those who have improper water treatment systems and live by the river)? Should they be limited to professional actors (including public authorities)? This type of questions and choices extend to several other variables.

Those thoughts could lead the reader to think that it is impossible to make definite choices. That may be the case but there are things that can be asserted with more certainty. Whatever the choice an analyst or a (group of) actor(s) makes between catchment and estuaries, these are the two possible relevant levels. A smaller system (such as for instance limiting the size of the resource system to oyster leases) would not make much sense since we are trying to tackle issues related to water, which flows freely in estuaries. If oyster growers are interested in water quality, they cannot limit themselves to leases or it would be a dead-end (but showing publicly that these are well taken care of could be a useful strategy, see Chapter 10). A larger system than the catchment could lead to two different directions that follow a political path (a political region that encompasses the catchment) or a physical one (such as a larger catchment basin). The latter could be tempting if the catchment basin was a subcatchment of a bigger river but we are dealing with coastal catchments exiting in estuaries. The former would induce to include even more elements than those listed at the catchment level and limit the ability to use the diagnosis. Complexity would be too important for the analysis to be clear and understandable. Table 7.3 shows consequences of system size choice for the resource and for actors.

It is important to remind that many choices are linked to the definition of systems. The example of the choice between catchment and estuaries illustrates this idea.

Table 7.3: Consequences on actors and resource of system size. Systems are nested.

System size	Actors	Water management
Oyster farm	Single	Impossible
Estuary	Oyster farmers, fishermen	Limited, mostly monitoring
Catchment area	Numerous and diverse	Hydrologically coherent
Larger	Too many	Too wide

7.5 Conclusion

In this chapter, I described estuaries and catchment basins. Oyster farmers use estuaries daily for their professional activities since their leases are located on such areas. Oyster farmers belong to catchment areas that exit in those estuaries. The catchment is an important source of water for the estuary and its quality is linked to water flows and practices from the catchment.

As suggested by the [SES](#) framework, to understand such a system, one needs to investigate several characteristics of the system that transcend disciplinary boundaries. Thus, I delved into the ecology of estuaries, and of oysters as a species that has an influence on their environment. Their influence is the one of an indicator species that has an action on nutrient levels, on turbidity, on microbiology, among others. Then, I described how oysters are grown when farmed.

These general elements provide a context that links both French and Australian cases and that could probably be applied to oyster farming around the world. In the next chapter, I describe more precisely the two cases, focusing on institutional elements as well as on information sharing systems. In [Chapter 9](#), I frame oyster farming questions using the goods and threats typologies.

Chapter 8

Two Cases - SES Analysis

This chapter is a follow up of the previous one that described the general ecology of oyster farming. I present in detail the cases that I investigated: the Thau Lagoon and several estuaries in [NSW](#). Using the material, I complete the [SES](#) analysis started in Chapter 7. For now, I insist mostly on variables that are useful locally whereas interaction, outcome and threat variables that will be addressed in Chapter 9. The use of the [SES](#) framework allows thorough description of the cases.

Describing local contexts is important to understand more precisely the situation the actors interact with daily. [SES](#) variables content for the two cases are given in Table 8.3. First, for both cases, I describe global settings such as history, geography, politics and institutional context, and then the information sharing artifacts that I studied. The first case that I delve into is the [NSW](#) one, then I detail the Thau Lagoon case.

8.1 New South Wales, Australia

8.1.1 History, economy, geography

[Schrobback \(2015\)](#) provides an up-to-date synthesis of the [Sydney Rock Oyster *Saccostrea Glomerata* \(SRO\)](#) history and economic importance in Australia. Oysters, and especially the native [SRO](#), have been eaten by aboriginal communities for thousands of years (A3)¹ ([White, 2001](#)). Oyster farming is the oldest aquaculture industry in Australia and in [NSW](#), starting around 1870 ([NSWDPI, 2013](#)). This type of aquaculture is the fourth largest aquaculture industry in Australia: in [NSW](#) it has been generating AUD33 million direct income for 318 license holders employing 1600 people ([OISAS, 2014](#)). The number of oyster farmers range from 3 to 30 depending on estuaries (A1). They

¹These codes are the variables codes in the [SES](#) framework, which can be found in Table B.1, p.260. The elements detailed in the following two sections are summarized in Table 8.3.

are usually organized in small to medium familial businesses (A2) (Schrobbach et al., 2014) and live close to the estuary they work in (A4). In 2013, 2,979 tons of oysters were commercialized (RS5) (NSWDPI, 2014).

In NSW, oysters are produced in 32 estuaries, shown in Figure 8.1. These estuaries are under growing urban pressure and competing usage by numerous types of users (S2). This situation is variable and demographic pressure is less important in Wonboyn River where the catchment (335.4 km² for a 5.6 km² estuary) hosts a single village of around 150 people than in the Lower Hawkesbury, with thousands of people living in this 21,624.1 km² catchment that contains a 114.5 km² estuary (GS3*). Issues are clearly different as well. There are 44 estuaries² bigger than 5 km² in NSW, and oysters are cultivated in most of the biggest estuaries in NSW: 26 out of these 44. (RS3) The biggest one is Port Stephens with a 134.4 km² estuary in a 296.8 km² catchment and the smallest is Nelson Lagoon with a 1.3 km² estuary in a 27 km² catchment. Sydney is located on the Georges River. From this point, two main regions are defined: the South Coast down to Wonboyn River and the North Coast, up to the Tweed River. These two extremes are distant by 1,400 km, and their climate are quite different, from temperate in Wonboyn to tropical in Tweed.

Water quality is assessed with *E. coli* rates in the water. Depending on the level of *E. coli* found all year around in an estuary, harvest areas are classified in several levels. These levels are adjusted every year (Regulation and Code, 2010, p.14):

Approved harvest areas: growers are allowed to harvest and sell oysters directly from the harvest area except in adverse conditions (heavy rain evens...) – not exceeding 14 cfu/100mL. Restricted harvest areas: growers are allowed to sell oysters after oysters are depurated in UV-treated water for 36 hours – not exceeding 70 cfu/100mL.

Approved harvest areas are the optimal estuary condition to manage oyster production, as growers do not need to take depuration time into consideration prior to market.

The oyster produced is overwhelmingly the native SRO. In 2012/13, the production of SRO generated \$31,844,593, while the PO generated a mere \$255,213 (NSWDPI, 2014), a value that has declined because of the Ostreid herpes virus (OsHV-1). This is linked to PO being considered as a noxious species in NSW. Oyster farmers are asked to remove this species whenever they see it in their estuary. This species is not considered noxious as it has been naturalized in Tasmania or in Victoria. Growing triploid PO is legal in 7 estuaries, and diploids can be legally grown in only one estuary (Port Stephens). Flat oyster *Ostrea Angasi* cultivation is anecdotal and gaining importance due to the herpes virus.

²<http://www.environment.nsw.gov.au/estuaries/list.htm>

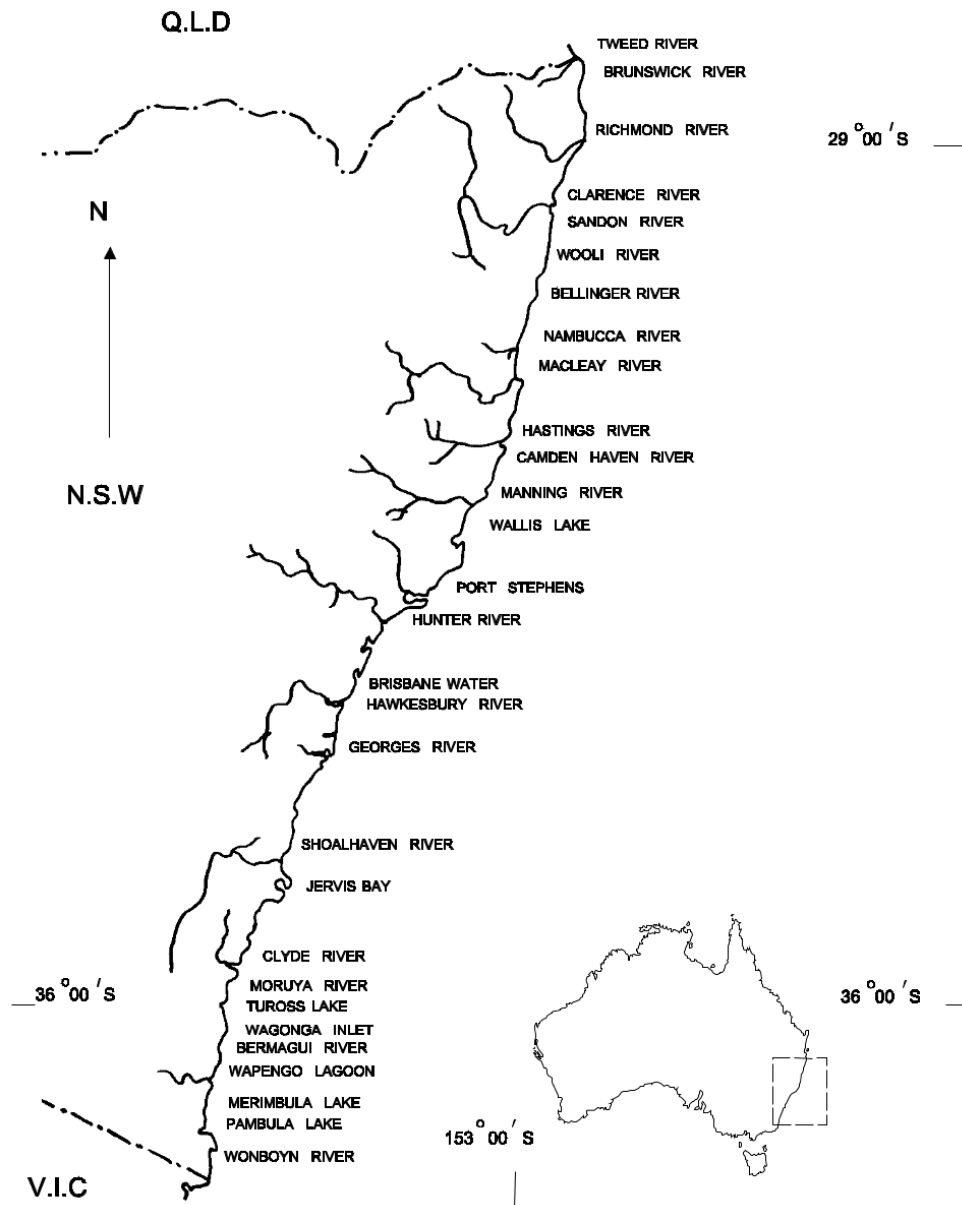


Figure 8.1: Major oyster producing estuaries in NSW (OISAS, 2014).

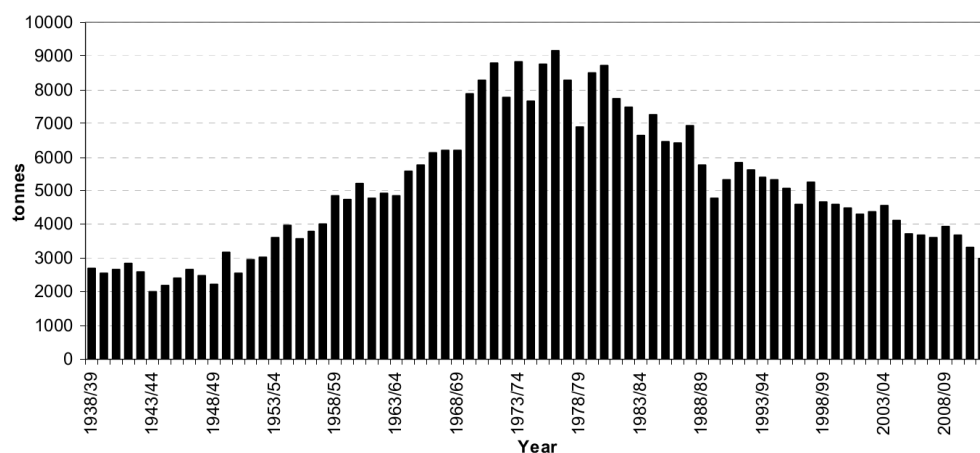


Figure 8.2: Oyster production levels in NSW (OISAS, 2014, p.6).

Husbandry practices differ from place to place. Several hatcheries exist that produce both SROs and POs be it from nurseries stock or from natural catchment. This business generated \$1,823,071 in 2012/13 (NSWDPI, 2014). Some oyster farmers buy their stock from these hatcheries, some catch their own oysters, some do both. Important hatcheries are located in Tasmania, Port Stephens and South Australia. Production methods differ, ranging from manual handling to mechanized processes. Cultivation can occur in a single place or be optimized by relocating oysters into estuaries with favorable properties at specific period of their lives. Viruses and other bacterias travel along with those oysters. Depending on their location, different markets are reached. The local one, Sydney, Brisbane for the North estuaries and even abroad.

Oyster farming production reached a peak in 1976/77 with 9,375 tons of oysters, and has followed a steady decline path ever since. Figure 8.2 shows the production trends of oysters in NSW from 1938/39 to 2011/12. This trend is explained in OISAS (2014, p.6):

This has been attributed to many factors including supply-side factors such as oyster disease, the effects of PO introduction and the degradation of water quality in many coastal rivers, estuaries and lakes.

Some of the estuaries that used to be the biggest producers have been almost entirely wiped out by such disease outbreaks, like Georges River, in Sydney harbor (from 2,566 tons in 1971/72 to almost 0 in 2014), or the Hawkesbury River (from 1,328 tons in 1969/70 to 285 in 2011/12) (OISAS, 2014).

8.1.2 Settings and institutions

8.1.2.1 Political settings and public institutions

(S1-S3-GS4*) Australia is a developed stable federal constitutional parliamentary democracy. Most of its population is located along the Ocean, especially in estuaries. As is in the United States, each state of the federation has important powers and is relatively independent from the others. There are six states, three federal territories and seven external territories. In this document, we will focus on **NSW**, one of the mainland states, since it is the location of the studied estuaries. **NSW** is divided into areas ruled by local councils. Some of these councils are gathered in institutions called **Local Land Services (LLS)**³ that replace former Catchment Management Authorities. There are 11 **LLSs** in **NSW**, with four of them along the coast (North Coast, Hunter, Greater Sydney and South East). **LLSs** are in charge of dealing with land matters such as developments, trainings, and communication with local communities. These nested organizations have defined responsibilities regarding environmental management. Some **LLSs** have been very active and supportive of oyster farming activities and developments such as South East **LLS** (Gietzelt et al., 2014), others have been less and are trying to catch up, as demonstrated in the workshop that I attended in Sydney (Section 5.2.2).

Apart from these institutions, oyster farmers have to deal with specific ones (GS1*):

New South Wales Department of Primary Industries (NSW DPI) “A division within NSW Trade & Investment and works to develop and sustain diverse, profitable food and fibre industries, and ensures best practice management of our natural resources” and more specifically for fisheries, it “develops, shares and protects the State’s fisheries resources through fisheries management, science and research, sustainable aquaculture development, habitat protection and regulation.”⁴

NSW Food Authority A division of **NSW DPI** that ensures that food is safe, “from production grassroots to retail” [Interview with Shellfish program manager, 2014]. This authority is responsible for temporary closure of estuaries when necessary. Moreover, the **NSW Food Authority** has developed a plan called the **Oyster Industry Sustainable Aquaculture Strategy (OISAS)** which has been used in this chapter and is presented in Section 8.1.3.1 (OISAS, 2006, 2014). They set best practice standards, and finance projects for or related to oyster farming. They make official maps of priority oyster and shellfish aquaculture areas, such as in Figure 8.3.

Within the Food Authority, oyster farmers participate in a program:

³<http://www.lls.nsw.gov.au/about-lls/what-we-do>

⁴<http://www.dpi.nsw.gov.au/aboutus>

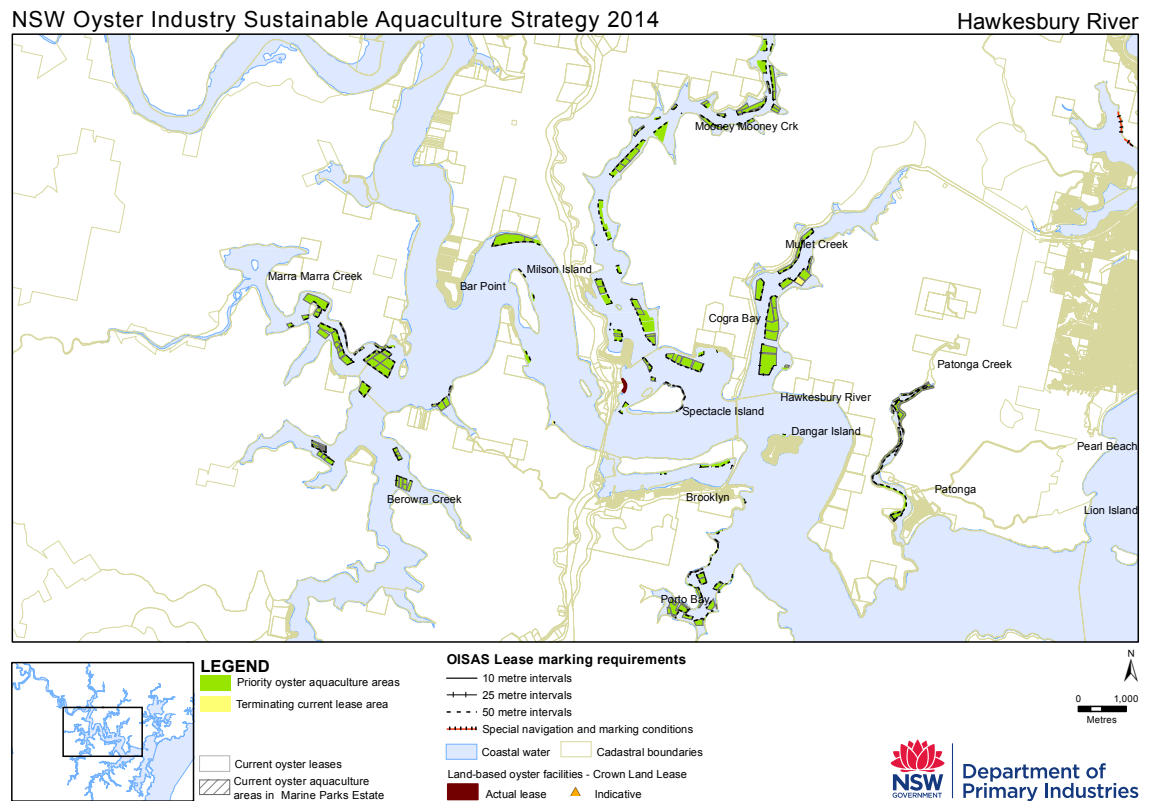


Figure 8.3: Lower Hawkesbury - Example of location of oyster leases and sheds, with property-right systems (RS9-GS7*)

NSW Shellfish Quality Assurance Program A section of the Food Authority dedicated to shellfish management, among which oysters. According to its manager that I had the opportunity to interview in November 2014 (all quotations in this paragraph come from this interview), they develop, in collaboration with oyster farmers, monitoring programs for the industry, sampling plans and local shellfish programs called [Quality Assurance Programs \(QAP\)](#) (see below). The local programs are half funded by oyster farmers in order to involve them. The program is well accepted by local oyster farmers since the manager spent two years mostly on the field (“I’ve been there since 2006, and for 2 years, I went to the farms, wearing my boots, jump in the water with them. I think they hadn’t seen that before. Like ‘what is he doing in the mud?’”. Talking to them, asking them questions, try to break down the barriers.”), building relationships with them, getting to know personally an important share of oyster growers, and especially building relationships with a group he can contact when he would like to implement a project or

a regulation. This narrative has been confirmed in several interviews with oyster farmers who said that relations with authorities have been much better in the last ten years. He says that in the end, “regulators and industry need some separation, but at the same time, government and industry want the same thing: they want a productive industry that creates jobs, economic activity and obtain a safe product. Industry does not want to make people sick. Government wants to help industry. They all want the same thing.”

Finally, a boundary-organization is of importance in the investigation.

OceanWatch This national non-for-profit environmental organization⁵ emerged from the fishing industry. I interviewed the manager of the [Environmental Management System \(EMS\)](#) program, an OceanWatch initiative. OceanWatch was initiated by a Sydney fishermen in 1989 who was worried about poor water quality. Their “work focuses on finding practical solutions to environmental problems that affect our coastal environments and estuaries. [They] also help commercial fishers take up new technologies and improved practices for a sustainable seafood industry.” They are in strong connection with farmers and public institutions, helping to bridge a gap between these actors. The main work done regarding oyster farming is helping to build [EMSs](#). They were also the organizers of the workshop I attended in Sydney (see Section 5.2.2).

8.1.2.2 Oyster farming institutions

An oyster farmer in estuaries can belong to several professional organizations adding to public institutions. Some are strictly for local and internal regulations and monitoring, others are more linked to lobbying, or to marketing. Here is a list of the relevant organizations I am aware of. For the local level, there may be little differences, but there would be no point in listing all existing local organizations. None of these institutions are compulsory for oyster farmers, except for the first one (GS5*-I6-I7).

Annual general meeting Every year, oyster farmers are compelled to organize a meeting in each estuary, elect a committee that organizes the [QAP](#) and decides over annual levees for monitoring and testing. It is the local counterpart of [QAPs](#).

Sapphire Coast Wilderness Oysters (SCWO) This association⁶, founded in 2011, emphasizes the role of oyster farmers as environment sentinels: they are everyday on the water and heavily depend on water quality. It

⁵<http://www.oceanwatch.org.au/>

⁶<http://www.sapphirecoastwildernessoysters.org.au/>

Table 8.1: Quality Assurance Program monitoring rules in NSW. All estuaries have more or less the same requirements with a variation on the number of testing sites depending on estuary size.

Seafood business section	Product to be tested	Variable to be quantified	Limit	Frequency of testing
Oyster grower	Cultivated oyster (in oyster lease)	<i>Escherichia coli</i>	<2.3 <i>E.coli</i> /g (direct harvest) <10 <i>E.coli</i> /g (restricted harvest)	After an event <i>i.e.</i> rainfall, sewer pollution, peak holidays (direct harvest areas) Every month (restricted harvest)
Oyster grower	Water from oyster harvest area (in lease)	Faecal coliforms	14 cfu/100 mL (direct harvest) 70 cfu/100 mL (restricted)	As per above
Oyster grower	Phytoplankton (from waters close to harvest areas)	Harmful algal species	As per Phytoplankton action limit included in the Biotoxin manual	Fortnight or during algal bloom
Oyster grower	Cultivated oyster (in oyster lease)	Paralytic, diarrhetic and amnesic shellfish; Poisoning toxins (PSP, DSP, ASP)	Presence of biotoxins	Fortnight if phytoplankton testing results positive
NSW food authority and oyster grower	Cultivated oyster (in oyster lease)	Heavy metals (arsenic, cadmium, lead, mercury...)	As per Australian standards	Every 5 years
Seafood processor offering ready-to-eat oysters	Opened oysters	<i>Escherichia coli</i>	< 2.3/g	Every 20 batches
	Packed oysters	<i>Escherichia coli</i>	< 2.3/g	Every 20 batches
	Cooked /smoked oysters	<i>Listeria monocytogenes</i>	Not detected in 1 g	Every 10 batches
All oyster processors	Non-reticulated water used in connection with the production and processing of oysters	<i>Escherichia coli</i>	Not detected in 100 mL	Not treated - every month / Treated - every 6 months

is dimensioned at the size of the local council of the Bega Valley Shire, encompassing estuaries from Wapengo to Wonboyn, in the South of the South Coast. Adhesion is voluntary and 19 oyster farmers across the four estuaries were members when this document was written. This association puts forward EMSs as an important element to legitimize their action and lobbying. Adding to this emphasis on environment, it acts as a marketing association, representing oyster farmers in local events such as fairs, and creating a quality brand for customers.

QAP (GS5*-I9) This program is designed as a monitoring program. There is one QAP per estuary. “This is a mandatory industry funded program designed to ensure that oysters are only harvested under strict water quality and product guidelines that seek to ensure that public health and high industry standards are observed and promoted.”⁷ The program is actually funded half by oyster farmers and half by NSW DPI. Monitoring is done on meat and on water (Table 8.1). Half of the funding comes from public resources since monitoring water is of public benefit for other uses as well [Interview with oyster farmer, 2014]. In the Hawkesbury River, the program costs AUD 40,000 to AUD 45,000, depending on rainfall events, to oyster farmers every year. This amounts to sampling 2 phytoplankton sites, 15 water sites and 12 oyster sampling sites at the frequency mentioned in Table 8.1.

Australia’s Oyster Coast (AOC) This association⁸ exists along the South Coast, has been founded in 2012 and gathers 45 growers across 8 estuaries. It is oriented towards marketing, mostly based on environmental excellence, and export. Local tourism development around oyster eating is also in the scope of the association through the creation of programs such as the oyster trail.

NSW Farmers This association⁹ is the main farming lobby in NSW. It features an Oyster Committee of 8 oyster farmers. They support the OISAS and the EMSs, and advocate different projects for oyster farming such as creating “a legislative framework which meets the needs of the oyster industry” (OceanWatch, 2014). Many projects regarding oyster farming as a whole are advocated by this association. At catchment levels, oyster farmers may be at odds with land farmers, but apparently, no such issues exist within the association [Interview with an oyster farmer member of the Oyster Committee, 2014].

⁷<http://www.dpi.nsw.gov.au/fisheries/aquaculture/publications/oysters/industry/oyster-industry-in-nsw>

⁸<http://australiasoystercoast.com/>

⁹<http://www.nswfarmers.org.au/advocacy/livestock/oysters> (membership is required for access)

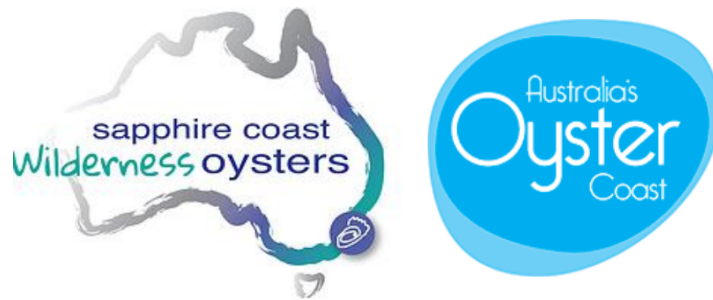


Figure 8.4: AOC and SWOC logos

8.1.3 Studied information sharing artifacts

(I2) In this section, I describe the artifacts that I studied with a particular emphasis. These artifacts that are not so common in *Natural Resources Management (NRM)*. The *NSW DPI* produces many different documents, aggregating information about production (*NSWDPI, 2014*), or about monitoring (*NSWFA, 2014*), among many others¹⁰. Amid these documents, the one that seemed the most interesting is the *Oyster Industry Sustainable Aquaculture Strategy (OISAS)*, which is described in the following section. Another kind of information sharing artifact that was often cited during the interviews was the *EMS*, developed by the oyster industry.

8.1.3.1 Oyster Industry Sustainable Aquaculture Strategy

The *OISAS*¹¹ is a publicly available document that was first written in *OISAS (2006)* and updated in *OISAS (2014)*. I interviewed the writer of this artifact, Tim Gippel, and in this section, quotations are from him. According to him, the need for such an artifact “came out because it was recognized that the industry was under a lot of pressure from increasing development on the coast and for the impact it was having on water quality, particularly the impact it had on sanitary water quality”. It was mainly written by the government. Once written, the authors asked oyster farmers to provide some feedback while explaining to them the goal of the document.

This document has had a different level of success among the growers, ranging from “never heard of it” to “I know whole parts of it by heart”. According to the author, it had another impact they did not predict, on the general public, who can read a well-structured document on what the industry does and how. This has the advantage of limiting complaints and making easier investment requests.

¹⁰<http://www.dpi.nsw.gov.au/fisheries/aquaculture/publications/oysters>

¹¹<http://www.dpi.nsw.gov.au/fisheries/aquaculture/publications/oysters/industry/industry-strategy>

The document is a self-constraining document for the government and local councils since oyster farmers can go and cite passages which are legally bounding. As the author says: “there has been a great deal of partnership that have grown between oyster farmers and councils”. This is the only document of this kind he is aware of, it does not exist in other states (“they would like to have one”) and it is the only industry who has it (“the chicken industry came and look at this saying they would like something like this”). “It is unique”.

It is structured as follows. First a vision statement announces the general view on the future of the oyster industry, emphasizing on sustainable development and links with environment. Then the industry is described, even though, much more is left to learn about the oyster industry in [NSW](#): a project is to be launched in 2016 to study socio-economic features of this industry, adding to the work recently done in [Schrobbach \(2015\)](#) PhD thesis. Then requirement and description of goals for healthy oysters and estuaries, water quality protection, aquaculture areas, environmentally sustainable practices and best practices are described. The document ends with a risk assessment.

8.1.3.2 Environmental management systems

Usually, EMSs are documents “part of the global management system which includes the organizational structure of the business, the planning activities to sustain the industry the responsibilities, the practices, the procedures, the processes and the resources necessary for development, implementation, achievement, evaluation and sustentation of the environment policy” ([Cotoc et al., 2013](#), p.1317). They help to “protect valuable environmental assets, manage local areas on the most suitable way and develop relationships between people and the natural environment” ([Mangra et al., 2014](#), p.1). They are organization-oriented: “an EMS has the primary purpose of preventing negative effects on the environment and improving a firm’s environmental practices” ([Massoud et al., 2011](#), p.6). EMSs can be taken to meet a certification standard or can be left as codes of practice. Two standards for certification exist: the ISO 14001 international standard and the CE regulation 1221/2009n environment and audit management ([Cotoc et al., 2013](#)). Literature shows that EMS implementation has positive outcomes for clients, costs (sparing unnecessary waste) and image ([Massoud et al., 2011](#); [Psomas et al., 2011](#); [Ronnenberg et al., 2011](#); [Cotoc et al., 2013](#)), that several strategies can be followed ([Nishitani, 2010](#)) and that small businesses have many more difficulties in EMS implementation, despite achieving positive outcomes ([Hillary, 2004](#); [Collins et al., 2007](#); [Zorpas, 2010](#)).

(I6-I7-I8-I9-I10-01-03-ECO2-ECO3) Within the [NSW](#) industry, [EMSs](#) have first been developed in this traditional way: some oyster farmers wrote an [EMS](#) for themselves. According to Andrew Myers, the OceanWatch [EMS](#) facilitator whom I interviewed in November 2014 (quotations in this section are from him), the first one to implement an [EMS](#) in [NSW](#) was an oyster farmer in

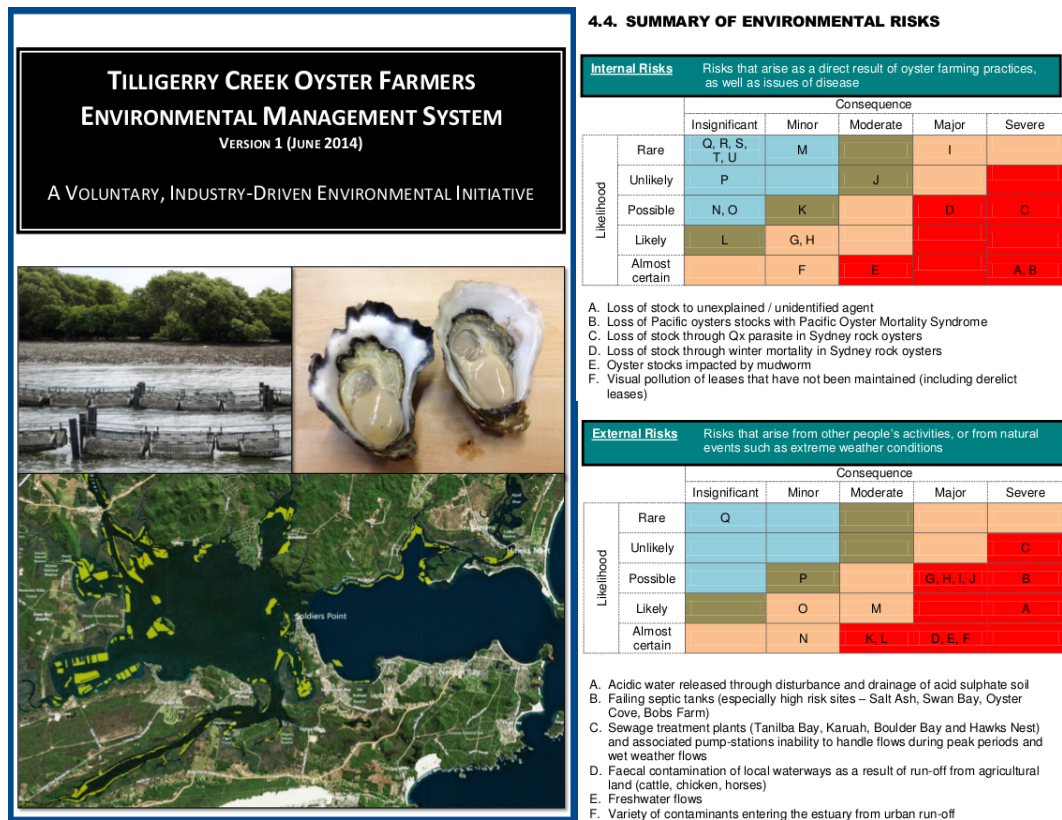


Figure 8.5: Front page and internal / external risk matrices of a typical EMS

the Hawkesbury River in 2004, right before the Qx virus hit (Section 9.2.2). This crisis got the remaining farmers together and they developed the first estuary-wide EMS in 2005/06. About the same time, an EMS was developed in the Clyde oyster growers. It was developed with OceanWatch as facilitator and the local LLS for financial support. After these two first experiences, the government announced in 2007 that grants would be available for oyster farmers who would implement an EMS and after 2010, grants were allocated for the development of estuary-wide EMSs. “Then it snowballed”.

There are two main aspects to EMSs: the first is “looking at how the industry can improve themselves, within the oyster industry, the other is looking at what is happening on the catchment that could impact the oyster industry”. In parallel, the government implemented program of grants: the grants obtained can finance up to 50% of a project and are distributed conditioned to the existence of EMSs.

As for the OISAS, this kind of estuary-wide documents are unheard of. There are numerous EMSs created at the farm level, but to my knowledge, there is no such thing as an industry-wide EMS in other industries.



Figure 8.6: Picture of oyster farmers in an EMS (EMSTilligerry, 2014)

Structure These documents are all publicly available in a database¹². A complete EMS consists in three main parts. The first and main one is a long (around 60 pages) document that is filled with information. The second one is a single page leaflet containing very general information and intended for a wide audience (Figure 8.7). The last part is a follow-up of the main document that is planned every two years.

The main documents start with a statement “a voluntary, industry-driven, environmental initiative” (Figure 8.5) that demonstrates the implication of growers in the project. The main goals are announced at the beginning: “demystify the industry and explain oyster farming practices”, “highlight the high risk activities to the local oyster industry”, “improve environmental performance of the industry and environmental conditions in [the estuary]” and “demonstrate that oyster farmers are continually improving their environmental performance” (EMSWagonga, 2012, preliminaries). There is also a signed commitment of oyster farmers of the concerned estuary, and often, a picture of all of them (Figure 8.6). Then, the local environment, estuary and catchment, as well as practices are described. After this, a detailed risk assessment is given, divided in two main parts: internal, “risks that arise as a direct result of oyster farming practices as well as issues of disease” and external, “risks that arise from other people’s activities, or from natural events such as extreme weather conditions” (EMSTilligerry, 2014, pp.28-29). For instance, the virus is considered an internal risk since it is only of concern to oyster farmers. The relation with the definition of threats given and investigated in this thesis is obvious and will be detailed in Chapter 9. All the identified risks, which actually correspond to the definition of threats (Section 3.1.1) by their scope, are analyzed, a probability of occurrence and resulting harm are associated with it, defining key consequences and ways to mitigate the threat, in association with indicators. This document is destined to “oyster farmers and local councils or

¹²<http://www.oceanwatch.org.au/our-work/ems-nsw-oysters/ems-database/>

Environmentally Sustainable

Brisbane Water oyster farmers have made a commitment to the environmentally sustainable production of oysters and to the ongoing protection of the estuary.

This commitment is outlined in the Brisbane Water Oyster Farmers Environmental Management System. The EMS is a voluntary initiative that outlines improvements that oyster farmers can make to their own operations, as well as how they can drive environmental improvements within the catchment.

Did You Know?

Oysters have been consumed by Aboriginal Australians for thousands of years with some shell middens dating back as far as 6,000 BC.

A Sydney rock oyster can filter 250,000 litres of water in it's life-time.

Each year, oysters commercially grown in Brisbane Water filter the equivalent of 80,000 Olympic swimming pools of estuary water.



How You Can Help

- Buy oysters from a reputable source. Oyster theft is illegal and carries significant penalties. Oysters sold through the black market are not quality assured and pose a risk to human health.
- Do not dispose of any waste into the estuary.
- Please do not travel through oyster leases or tie-up to marker posts. This can damage infrastructure that is expensive to repair and replace.
- Report pollution incidents to the NSW EPA Environment Line on 13 15 55.

More Information

If you have any questions about oyster farming in Brisbane Water, or would like a copy of the Brisbane Water Oyster Farmers Environmental Management System, please contact Denise Whitten Whittenoysters@gmail.com

This project is supported by Brisbane Water Oyster Farmers and OceanWatch Australia through funding from the Australian Government



Oyster Farming in Brisbane Water



Brisbane Water Oyster Industry

Map: Oyster leases in Brisbane Water



Brisbane Water is located on the central coast of NSW. The estuary system is home to about 15 oyster farmers who commercially grow shellfish over 151 hectares of designated lease area.

Brisbane Water oyster farmers grow the iconic Sydney Rock Oyster. In 2012-2013, the local industry produced 1.8 million oysters, worth over \$800,000 at the farm gate.



A rigorous quality assurance program ensures oysters commercially harvested are safe for us to eat.

Quality Assurance Program

Oysters are filter feeders, straining plankton, suspended solids and inorganic particles from the water. This makes them excellent indicators of estuary health.

To ensure that cultivated oysters are safe for us to eat, farmers maintain a rigorous quality assurance program. This includes fortnightly water and meat testing, with additional bio-toxin assessments conducted once a month.

The data collected also provides an invaluable record of changing environmental conditions, and contributes significantly to our understanding of the waterway and its management.



Oyster Farming Practices

Oysters begin their lives as free-swimming larvae. While some local farmers collect larvae themselves, Brisbane Water is not recognised as a good catching estuary. Most farmers therefore catch larvae in other estuaries, or buy juvenile oysters off other farmers elsewhere in NSW.

After catching or buying juvenile 'spat', most farmers use trays, or long-line systems to grow oysters until they are big enough to harvest.



Oyster trays
Oysters are grown in trays which sit on racks installed in the estuary



Long-lines of floating bags
Oysters are grown in containers that are secured onto long-line structures

Figure 8.7: Example of EMS leaflet - Brisbane waters

very interested random people”. [EMSs](#) go into much details for internal risks, listing up to dogs barking making too much noise for neighbors. As explained in Chapter 7, oyster farmers act in intrinsically open systems. External issues are of more importance (see risk matrices of Figure 8.6: rare and insignificant internal risks are numerous; and almost certain and severe internal risks are linked to viruses and pests) than internal. This element may be explained by a willingness to demonstrate how much efforts oyster farmers make, with the intention of convincing others to make efforts on their side.

The leaflet (Figure 8.7) presents in a very general and accessible way the main principles of the [EMS](#), such as what the oyster farmers are doing for the environment and how one can help. These leaflets are available in places like local tourist information booths, or camping sites. The updates are designed as follow-up documents where oyster farmers aggregate information to fill the indicators they defined in the risk assessment matrix. They then use this document to improve and update the general [EMS](#) or add new information that was previously lacking.

8.1.4 Conclusion - NSW

In this section, I described the general background [NSW](#) oyster farmers evolve in and the information sharing artifacts that they devised. Oyster farming is present all along the [NSW](#) coastline, including the most important estuaries. Oyster growers have to interact with numerous internal and external institutions. The [OISAs](#) and the [EMSs](#) are artifacts that are quite versatile and are often used, both at the internal level for the oyster industry and at the external level when there is a need for interaction with other actors (government, developers, communities). In Chapter 10, I will investigate how growers used the documents to deal with public threats.

Now let us turn to the Thau Lagoon case which is similar due to the prevalence of oyster farming in the Lagoon, but which presents important differences, as pointed out in Section 8.3.

8.2 Thau Lagoon, France

In France, I focused on a single [SES](#): the Thau Lagoon. A recent synthesis of issues and perspectives for the future of the catchment is available in French in [SAGE-Thau \(2015\)](#), a comprehensive planning document written by the very active local public authorities¹³. A great part of the following information comes from this document and from reports resulting from projects such as [Abadie et al. \(2004\)](#). When no reference is indicated for a figure, it comes from [SAGE-Thau \(2015\)](#).

¹³Section 8.2.2 argues why this document can be considered as a reference for the catchment area.

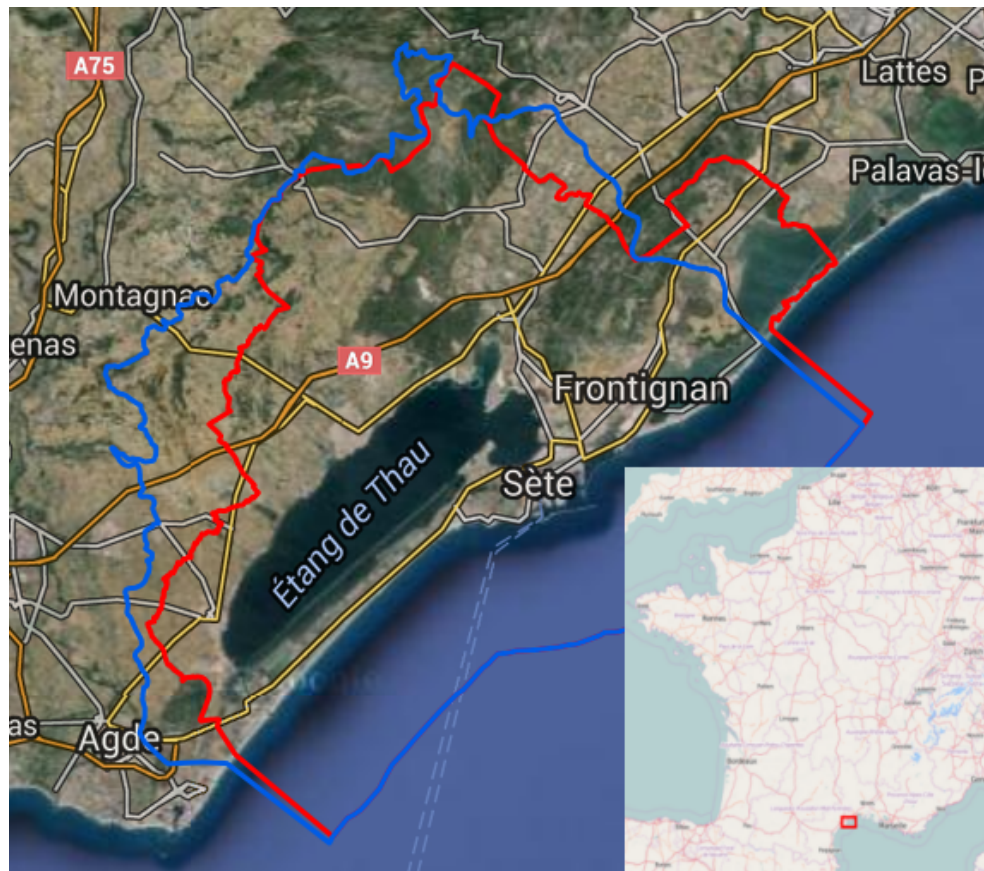


Figure 8.8: Thau catchment area - The blue line is the limit of the local water management scheme which correspond to the catchment area. The red line is the limit of the local urban development scheme. Source: <http://www.smbt.fr/espace-carthographique>

8.2.1 History, economy, geography

The Thau Lagoon is located in the South of France, on the Mediterranean coast (RS9). This 7,500 ha lagoon is almost separate from the sea by a narrow band of land called *lido* and is not subject to tides (there are almost no tides in the Mediterranean sea) (RS3). It is located within a catchment of 418 km² where 126,657 people lived in 2012 creating a strong urban pressure (18.5% of urbanized areas) which is to be under better control thanks to new development schemes (S2). In the catchment, there is one main city, Sète, founded in this location since it was possible to develop a deep water harbor which is still important in the local economy. Sète is the 11th French harbor with 3,5 million tons of goods traded in 2012 [PortSète \(2013\)](#) and a fishery. The lagoon is directly accessible through 5 villages (plus Sète) that all have water access through small harbors to the lagoon. It is crossed by a former important

trade canal, the canal du Midi (a UNESCO site¹⁴) and the canal du Rhône à Sète, which links the Mediterranean sea and the Atlantic Ocean. Now it is mostly used for tourism and generates a non negligible revenue for the region.

The Thau Lagoon is used by fishermen, oyster farmers and tourists both on boats and as bathers. This area is supposed to give priority to fishing and oyster farming activities and thus to water quality monitoring and improvement (SAGE-Thau, 2015, p.71). (A1) 497 license holders work along the shore of the Thau Lagoon employing 2,000 people. (A2) 94% of firms have less than 5 full-time workers (including the owner) and even 58% of them employing no one else (Gervasoni et al., 2011). (A4) The sheds are located in 5 main harbors (Mèze, Marseillan, Loupian, Sète and Bouzigues) and tables occupy 2,000 ha. (RS5) They produced 8,200 tons of oysters and 3,500 (plus 2,000 in the sea) tons of mussels in 2011 that represent 90% of total production in the Mediterranean and 10% of French production, generating € 26.1 million directly and € 86.7 million including trade (Gervasoni et al., 2011). (A8) 42% of producers have another activity, mostly (59.5% of them) fishing.

(GS10*-A3) There has been traces of oyster growing back to the Romans but professional oyster farming started during the 19th century and really kicked off after 1945 (Giovannoni, 1995). Competing with fishermen, oyster farmers got increasingly more surface on the lagoon for their tables and oyster growing reaching 2,000 hectares of oyster leases (RS3). Things were running smoothly when, in 1975 (and then in 1982, 1983, 1987, 1990, 1997, 2004, 2007), a very important “malaïgue” (bad water), a destructive anoxic crisis, occurred. This was the first blatant sign of poor water quality. The lagoon is the main reception basin of all water coming from catchment, with rain run-off passing through farms, and towns. Another sign of poor water quality was the ban of sales in 1989 linked to important *E. coli* rates in water (Sécolier, 2009). As shown in Table 8.2, the number of days of closure can be important, up to 113 days in 1999. Because of these events, the grade attributed to the lake is B (corresponding to restricted harvest area) since 2003 (the best being A) which forces oyster farmers to depurate their oysters for at least 48 hours in depuration basins before selling them for consumption. The A grade (corresponding to approved harvesting areas) enables selling directly after harvesting. Results are getting better thanks to numerous investments such as in water treatment plants (SAGE-Thau, 2015). This can be seen in Table 8.2: the number of closures dropped significantly since 2007. An oyster farmer that I interviewed, formerly researcher at Institut Français de Recherche pour l’Exploitation de la Mer (Ifremer), was even worried that this treatment would lead to a dead lagoon with no nutrients whatsoever entering the lagoon since oysters are filter feeders (Section 7.2). Indeed, water treatments, especially when rain water is also treated, destined to limit *E. Coli* rates affect also other elements that are necessary to life.

¹⁴<http://whc.unesco.org/en/list/770>

Table 8.2: Closures in days of the Thau Lagoon - The lagoon has been downgraded in 2007 to B category

Year	E. Coli	Alexandrium	Total
1998	30	22	52
1999	113	0	113
2000	104	0	104
2001	0	28	28
2002	34	19	53
2003	34	0	34
2004	25	0	25
2005	8	0	8
2006	49	0	49
2007		0	
2008	12	0	12
2009	0	0	0
2010	0	0	0
2011	54	0	54
2012	12	0	12
2013	0	0	0
2014	29	0	29
2015	0	0	0

Production is oriented towards POs that represent 99% of French production (Oden et al., 2011), and a few flat oysters, after a virus decimated the formerly grown Portuguese oyster, *Crassostrea angulata*, in the 1970s. There are no local hatchery: spat is bought and imported from hatcheries or nurseries located along the Atlantic coast. 97% of oyster farmers buy oysters from hatcheries, 28% only triploid PO (Gervasoni and Ritter, 2014). Attempts of local natural catchment have started in 2009 and show promising yet unstable results (Rayssac et al., 2011). Producers are thus dependent on external production basins for their activity. Since 2008, POs have been affected by Ostreid herpesvirus (OsHV-1) (Pernet et al., 2012, 2014) that kills 54% of oysters on average, with 88% of producers reporting between 25 and 75% mortality rates (Gervasoni and Ritter, 2014).

(A6) According to several interviews, producers are quite independent from each other, with limited communication, little or no contacts with others, competing for retail prices. Oyster farmers said that they led their businesses as they intended and did not need to work with others. An example of this behavior was given by an oyster farmer who testified that several attempts of coordination on retail prices failed because of free-riding: there was always someone who yielded to sell at lower prices. Network structure is thus quite

loose, mostly limited to close neighbors (sheds are close by) but the methodology used is not sufficient to strongly derive network results (GS9*). When I introduced the subject of information sharing, an oyster farmer cut me off saying “Ah ... information sharing ... First, we need to know each other, because we do not know each other, that is the problem”. Other oyster farmers answered in the survey that “we should be more able to communicate our practices with local people” or that “we should broadcast to a more general public what we do”.

8.2.2 Political setting and structured institutions

(S1-S3-GS4*) France is a constitutional stable and developed democracy with a tradition of strong state power.

France is part of the European Union which has strong requirements for water quality, especially through the [Water Framework Directive \(WFD\)](#) (Directive 2000/60/EC).

The [WFD](#) introduced in 2000 new and ambitious objectives to protect and restore aquatic ecosystems as a basis for ensuring the long term sustainable use of water for people, business and nature. The [WFD](#) has incorporated into a legally binding instrument the key principles of integrated river basin management bringing together economic and ecological perspectives into water management. ([WFD, 2012](#), p.3)

Previously mainly managed by the state, French local authorities became increasingly more prominent due to decentralization laws ([Schmidt, 2007](#)). There are numerous public organizations that overlap each other or not. This (very) complex organization can be simplified by saying that there is a central state, regions, departments, inter-communal authorities, and municipalities. Those organizations are nested and have different roles. The Thau lagoon, is located into the Languedoc-Roussillon region, in the Hérault department, and is under the supervision of two inter-communal authorities, one in the North (Communauté de Communes du Nord du Bassin de Thau - 6 municipalities) and one in the South (Thau Agglo - 8 municipalities). Those 2 inter-communal authorities divide the Lagoon in two parts, North and South.

Due to this division and local rivalries, there was a deadlock on development schemes after the failure of local organizations that failed to be recognized as legitimate such as Apogée ([Maurel, 2012](#)). The State then requested the creation of a local management structure called the [Syndicat Mixte du Bassin de Thau \(SMBT\)](#) in 2005, a territorial engineering structure, which was to be in charge of the development of local development schemes such as [Schéma d'Aménagement et de Gestion des Eaux \(SAGE\)](#) for water management ([SAGE-Thau, 2015](#)), or [Schéma de Cohérence Territoriale \(SCOT\)](#)

for land planning. The limits of the **SAGE** and the **SCOT** broadly coincide (Figure 8.8). They correspond to the catchment area of the Thau basin (not counting underground aquifers). This point enables coherent political decisions at an adapted scale (Buller, 1996) since spatial (catchment), administrative (local), institutional (laws, regulations), management (strategies), information (between positivism and constructivism) and stakes are logically framed (Daniell and Barreteau, 2014). This correspondence is not general in France.

An important point for the **SMBT** is participation of professionals and general public so as to gather different points of view and interests. Members of **SMBT** emphasize participation for the creation process of the documents described above (SMBT, 2012). To build **SCOT**, the **SMBT** organized 12 public meetings paired with a mobile exhibition, numerous meetings with local stakeholders, especially fishermen and oyster farmers who are considered particularly important regarding water management (SMBT, 2012).

(S4) Adding to these local political institutions, oyster farmers have to deal with specific institutions:

Direction des Affaires Maritimes (marine authority) Depends on the Ministry of Ecology, sustainable development and energy. It¹⁵ is the authority in charge of security and use of waters. It also helps local authorities to deal with these matters. For oyster farmers, it deals with certification and license issues, thefts and pollutions.

Agences de l'eau (water agencies) Those agencies (Rhône-Mediterranean-Corsica in the case of Thau) are in charge of monitoring pollutions and contribute to sustainable management of water resources. They write documents called SDAGEs¹⁶ which are the base for writing local **SAGEs**.

Ifremer This research institute “through its research work and expert advice, contributes to knowledge of the oceans and their resources, to monitoring of marine and coastal environments and to the sustainable development of marine activities. To these ends, Ifremer conceives and operates tools for observation, experimentation and monitoring, and manage the oceanographic databases.”¹⁷ It is the competent authority to decide over water monitoring, and can decide temporary closures and sell bans (I9). It has led researches for the oyster industry such as impact of oyster farming (Deslous-Paoli et al., 1998), socio-economic attributes (Gervasoni et al., 2011), mortalities (Gervasoni and Ritter, 2014) and is currently leading research projects for diversification (other shellfishes) and natural catchment in the Thau basin.

¹⁵<http://www.dirm.mediterranee.developpement-durable.gouv.fr/>

¹⁶<http://www.eaurmc.fr/le-bassin-rhone-mediterranee/le-sdage-du-bassin-rhone-mediterranee.html>

¹⁷<http://wwz.ifremer.fr>

Cepralmar This public institute¹⁸ created at the regional level has three main missions extending over the Mediterranean coast (Cepralmar, 2007): help professionals and industry develop their projects, foster a sustainable and integrated management of the coast, facilitate participation and dialogue between actors (professionals, users, public sector, researchers) over projects and development. Among their projects lies the “Réseau de Suivi Lagunaire” (RSL¹⁹) which aims at monitoring lagoons along the Mediterranean coast, specifically regarding eutrophication. This network is publicly funded.

(I6-I7-I8) At national and local levels, oyster farmers have a lobby, to which they are compelled to be members of, to defend their interests: the Comité National de la Conchyliculture and the [Comité Régional de la Conchyliculture de Méditerranée \(CRCM\)](#). They lobby for oyster farming role in the lagoon, against users such as marina developers or leisure boaters for instance. They can work with fishermen, through the fishermen organization called prud’homies or against them depending on the subject. [Giovannoni \(1995\)](#) offers a fascinating exploration of the Thau fishermen. According to the director of the [CRCM](#) “there is a global tendency towards collaboration now since they both face similar issues and many oyster farmers are fishermen as well”. There are even sea breams that eat oyster spat wreaking havoc for growers which leads to increasing collaboration, an example of low excludable and highly internal threat for oyster farmers which is a common-pool resource for fishermen. The [CRCM](#) leads local collective projects such as collective storage in the sea. They hardly succeed because of lack of oyster farmers will for projects like these. “All that can be done at the individual level is done at the individual level” (interview with [CRCM](#) director, 2014). It also has a marketing purpose through defense of image of product (which is already high). The [CRCM](#) tries to defend oyster farming as a sustainable practice using lines such as “oysters filter water and thus participate in water purification”.

The survey that I designed intended to investigate oyster farmers knowledge and opinions about [CRCM](#) actions. Unfortunately, this survey failed to be launched because of [CRCM](#) direction blocking it (Chapter 5).

8.2.3 Studied information sharing artifacts

The information sharing system that first drew my attention is the formerly named OMEGA Thau project, now *VigiThau*, that I present first. I also studied other artifacts that I introduce afterwards. I would have liked to explore deeper these artifacts, using the failed survey. Because of the limited number of responses, I only use qualitative elements of the survey. Even without the

¹⁸<http://www.cepralmar.org>

¹⁹<http://rsl.cepralmar.com/>

survey, it is interesting to know that these information sharing artifacts exist to compare with the [NSW](#) situation.

8.2.3.1 OMEGA Thau

This project, started in 2007, has been developed within the [SMBT](#) and has accomplished important progress to this date. OMEGA is an acronym for environmental management and warning tool for the Thau Lagoon. The [SMBT](#) consulted scientific researchers, local authorities, professional fishermen and oyster farmers (through the [CRCM](#)). Three main goals are cited for the project ([Brocard et al., 2010](#)). The first one is to understand better source and transfer mechanisms for microbiological pollutions from the catchment to the lagoon. The second is to create a decision aid for public investment taking into account what is defined as the top priority for the region: excellent water quality (highlighted in [SAGE-Thau, 2015](#)). Last, it enables the creation of an early warning system (Figure 8.9) of upcoming pollutions for users, swimmers, fishermen or oyster farmers as can be seen in figure using a combination of weather forecast, models and data.

Important data collection, model creation and fitting work was done during the last 8 years resulting in a usable prediction tool that fits the three established goals ([SMBT et al., 2009](#)). In the end, the project has led to the definition of a new measure called the *maximal admissible flow* (MAF) for *E. coli* ([SMBT et al., 2010](#)). This step is now over. A new step is considered now: using the same water flows model to predict and understand possible floods.

The artifact is mostly using the model to simulate flows in an automatic manner. Warnings are transmitted to [CRCM](#) who give the information to grassroots oyster farmers. The model allows for a fine granularity and precision in water flows, leading to accurate predictions in different areas of the lagoon. Figure 8.9 shows those predictions in different part of the lake, for shellfish harvesting or collecting, as well as swimming conditions. The model estimates these levels up to 5 days. Normal access to the platform gives this type of information. Information *per se* is not given by actors but by a network of sensors distributed around the catchment and in the Lagoon. Users can give specific observations of potential risks to water. This artifact is dynamic: updated in real-time, and predictions change everyday.

Interviews with oyster farmers occurred from April to June 2014. This period was the calibration phase of the website. The project had been going on for 7 years already. None of the oyster farmers, except the ex-researcher, and one who is a member of the [CRCM](#) told me they knew about the project when I asked them. They often told me that they doubted it would be of any use, or at least that they would use it. Their argumentation was put in the following manner. Microbiological blooms lead to temporary sell bans, but do not harm the oysters. Since oysters need depuration, they have water depuration basins, which can be used for a limited storage. For now, they

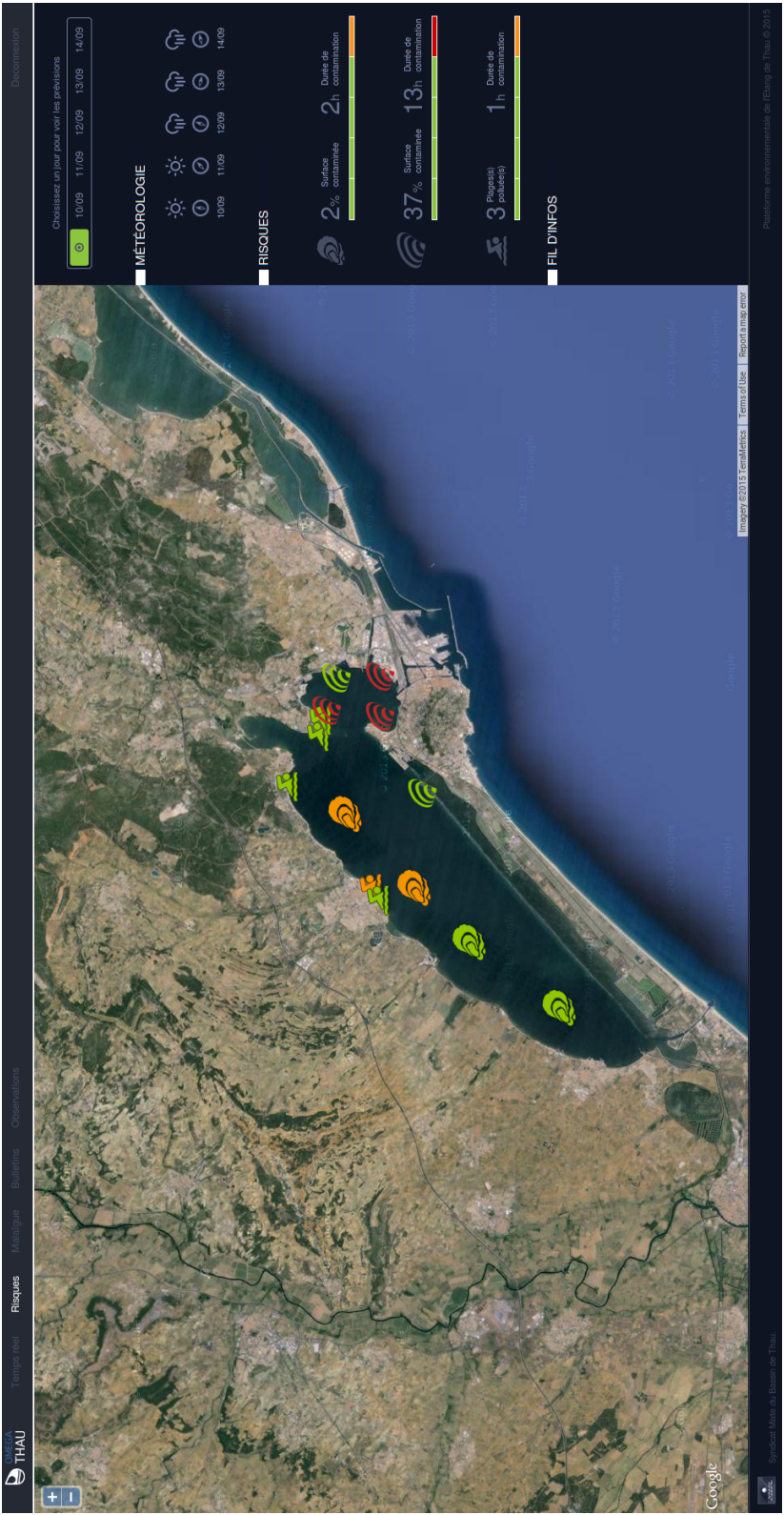


Figure 8.9: OMEGA Thau webpage - Previsions of water quality for shells and swimming.

use weather forecast to decide over storing oysters for a few more days. Since the microbiological flows cannot be predicted for more than a few days, this information would not be an important advantage. Some even feared that this would lead to more regulations.

The OMEGA Thau project was presented to the public during a workshop organized in Sète on September 25, 2015.

8.2.3.2 Other artifacts

Three other artifacts seemed to be the closest to collective action documents. I intended to explore how much oyster farmers know and use them using the survey. Since only a few oyster farmers answered the survey, in the analysis I only use the comments that they wrote down and not the statistics.

Crisis management protocol This document is destined to help oyster farmers react quickly in case of crisis. According to the few answers, this document is well-known and used by oyster farmers.

Guide for oyster farming in Languedoc-Roussillon This beautifully made guide is destined to all oyster farmers, especially new comers. It contains all kinds of information, regulations and advice for good practices (Cepralmar, 2008). The guide is very accessible, illustrated with nice pictures and quite appealing. According to the acknowledgment section, 7 oyster farmers were consulted as well as numerous people from different organizations.

Guide for good practices for oyster farming This document is close to EMSs. It contains a risk assessment and recommendations for best practices (Berger et al., 2007). Risks are listed in two categories: global impact of the industry and individual impact linked to practices. It is the result of an internship and was made by interviewing different types of local actors, including quick interviews of 38 growers and deeper investigation with 4 oyster farmers.

8.2.4 Conclusion - Thau Lagoon

In this section, I described the Thau Lagoon case where 500 oyster farms are located in a catchment with significant urban pressure and farming activities. Oyster farming is a major activity that has considerable social and economic local consequences. Local authorities have developed an early alert system called OMEGA Thau that can be helpful for oyster farmers to improve risk management. Other artifacts have been developed as well. However, there seem to be little interest and intended use of these artifacts.

Let us now compare the two cases and begin to understand how close and yet different they are.

Table 8.3: Comparison of SESs in NSW (globally) and Thau Lagoon. SES boundaries are limited to oyster farming related elements. Most of those elements are discussed in more details in the previous sections.

I removed Resource Units variables since they are exactly the same, refer to Table 7.1, p. 106 and Resource Systems variables which have been discussed in Table 7.2, p. 110.

Variables with a † refer to variables proposed in Chapter 3, see Table 3.6.

Variable	NSW	Thau Basin
S1 - Economic development	Developed	Developed
S2 - Demographic trends	From sparsely populated to important urban pressure	Very important urban pressure
S3 - Political stability	Stable democracy	Stable democracy
S5 - Markets	Local, Brisbane, Sydney, Melbourne, international	South of France
S6 - Media organizations	ABC Rural, Fish magazine (Fisheries Research and Development Corporation), fisheries newsletters	Local newsletter but not distributed (interview with oyster farmer), CRCM blog http://www.srcm.fr/blog/
S7 - Technology	From manual handling to automatic processing - Triploids in a restricted number of estuaries	From manual handling to automatic processing - Triploids
GS1* - Policy area	Environment	Environment
GS2* - Geographic scale of GS	Varying from 1 council for several catchments (e.g. Bega Valley Shire) to several councils per catchment (Lower Hawkesbury)	SMBT at the catchment level
GS3* - Population	From 150 to tens of thousands	120.000 under SMBT jurisdiction
GS4* - Regime type	Democratic	Democratic
	<i>GS5* - Rule-making organizations (see previous sections)</i>	
GS5a* - Public sector	NSW DPI, Food Authority, Shellfish program, LLS , councils	SMBT, Ifremer, Marine authorities, water agencies
GS5b* - Private sector	Oyster farmers businesses	Oyster farmers businesses
GS5c* - Nongovernmental	SCWO, AOC, NSW Farmers	CRCM, CRC (national body)
GS5d* - Community-based	QAP, Love our lakes	Cooperative des 5 ports

Continued on next page ...

Table 8.3 – continued from previous page

Variable	NSW	Thau Basin
GS5e* - Hybrid	Ocean Watch	Cepralmar, local commission on water (CLE), CGI
<i>GS6* - (Significant) rules-in-use</i> - See EMSTilligerry (2014) for NSW or Cepralmar (2008) for Thau		
GS6a* - Operational	Sell bans due to poor water quality	Sell bans due to poor water quality
GS6b* - Collective-choice	Water monitoring rules	Water monitoring rules
GS6c* - Constitutional-choice	Zoning	Absence of zones
GS7* - Property rights system	Private leases on designated areas of estuaries which are crown-land	Private leases, with access to area restricted to licensed oyster farmers on a public estuary
GS8* - Repertoire of norms and strategies		
GS9* - Network structure	From few relationships to clique	Relatively few relationships with others, mostly limited to neighbors
GS10* - Historical continuity	Up to 180 years continuously	Started around 1900 with boom after 1945
A1 - Number of relevant actors	From 1 to 30	500
A2 - Socioeconomic attributes	From father to son and newcomers	From father to son and newcomers - Low formal education
A3 - History or past experiences	Virus crises	Virus crises
A4 - Location	Near production area	Near production area
A5 - Leadership / entrepreneurship	Some proactive growers (e.g. those responsible for EMS)	Some leaders with charisma / Innovation (new culture techniques)
A6 - Norms (trust-reciprocity) / Social capital	Trust is being built (Chapter 10)	Little trust, gather when threats arise
A7 - Knowledge of SES / Mental models	See Tables 10.1 and 10.2	From quite focused on their farm to global catchment vision
A8 - Importance of resource (dependence)	Only source of income for some, coupled with fishing, restaurant and other activities for others	Only source of income for some, coupled with fishing, restaurant and other activities for others
A9 - Technologies available	Stick culture, tray culture, baskets, rafts ... see EMSTilligerry (2014)	Tray culture, baskets ... see Cepralmar (2008)
I1 - Harvesting	Independently done by each farmer on their farm	Independently done by each farmer on their farm
I2 - Information sharing	Word of mouth, monitoring, newsletters (Ocean-Watch), EMS	Word of mouth, chief of harbor, commissions, text messages

Continued on next page ...

Table 8.3 – continued from previous page

Variable	NSW	Thau Basin
I3 - Deliberation processes	Meetings every year	Little or through representatives
I4 [†] - <i>Threats to collaboration</i>	Thefts	Thefts, competition on prices
I5 - Investment activities	Depollution activities	Collective water basins, underwater turbines (only projects)
I6 - Lobbying activities	Marketing,	Through CRCM and various commissions
I7 - Self-organizing activities	Creating the EMS and following proposed actions	
I8 - Networking activities	Via Catchment Management Authorities and marketing organizations (AOC , SCWO)	Through CRCM
I9 - Monitoring activities	QAP (Table 8.1)	Through Réseau de Suivi Lagunaire
I10 - Evaluative activities	EMS and Annual General Meeting	Veterinary, public monitoring
O1 - Social performance measures	Evolution of number of farmers, income, loss due to closures	Evolution of number of farmers, income, loss due to closures
O2 - Ecological performance measures	Water quality, mortality, closures	Water quality, mortality, closures
O3 - Externalities to other SESs	Limit eutrophication	Limit eutrophication
ECO1 - Climate patterns	Warming and increase of extreme events in regards to rainfall/storms	Warming and increase of extreme events in regards to rainfall/storms
<i>ECO2a[†] - Non internal pollutions</i>	<i>ECO2[†] - Public threats</i> Microbiological flows, sewage overflows, fertilizer run-off	Little
<i>ECO2b[†] - Facilities</i>	Sewage treatment plants, tourism facilities	Sewage treatment plants, tourism facilities
ECO3 - Flows into and out of focal SES	Boats (tourism, fishing), water	Boats (tourism, fishing), water

8.3 Discussing the cases

In this section, I compare broadly the two cases, pointing out the main differences using the variables proposed in the [SES](#) framework.

Table [8.3](#) compares the Thau Lagoon and [NSW](#) cases using the [SES](#) framework. Since there are several [SEs](#) in [NSW](#), ranges are given instead of specific values. I chose to describe the [SES](#) at the estuary (including the shore) level instead of the catchment one, so as to focus on oyster farming mostly. Section [7.1](#) gives an overview of the consequences of this choice.

Elements provided in this table come from various sources. First, they come from official oyster farming artifacts, mostly those listed in the previous sections, such as [EMSs](#) (*e.g.* [EMSTilligerry, 2014](#)) and the guide for good practices ([Cepralmar, 2008](#)) in which rules, technologies, property-rights are listed or evoked. Contextual elements such as in Governance System are sourced in official documentation such as [SAGE-Thau \(2015\)](#) or [OISAS \(2014\)](#). Some elements are linked to actors perceptions or beliefs. I filled these variables using mostly interviews and meetings with actors (oyster farmers, public servants, and researchers) that gave me a range of possibilities. I also used official statistical studies for hard figures, such as [Gervasoni et al. \(2011\)](#).

This table shows that those cases are relatively similar. This should not come as a big surprise given all the elements exposed in the previous chapter on the ecology of oyster farming. Oyster farmers are subject to the same kind of threats, oysters grow in estuaries and growing techniques do not come with an important variety. [PO](#), diploid or triploid growing is subject to restriction in part of [NSW](#) estuaries, while it is approved in Thau. In both countries, most spat is produced in an industrial manner in hatcheries.

A first major difference between those cases is the question of size. In [NSW](#), there can be up to 30 growers in one estuary, while in Thau, 500 businesses are active, employing 2000 people. This particular point is extremely important regarding interactions and thus outcomes ([Nagendra and Ostrom, 2014](#)). Information sharing, processes leading to artifact creation, conflicts and solidarities vary due to this element. Information sharing is at the core of this thesis, differences will be discussed in detail in Part [IV](#). It is impossible for Thau oyster farmers to know in person all other farmers, while a complete network may exist in [NSW](#) estuaries. As it is visible on the map (Figure [5.1](#), p.[74](#)), oyster farmers are not located in a uniform manner along the shores of the Lagoon. They are organized in patches, often with more than 30 oyster farmers, but with more reasonable number of farmers than on the whole Lagoon.

A second important point to keep in mind while trying to investigate actor's role in water management is the concept of community. A community can be defined as "a group of people living in the same locality and under the

same government”²⁰. This concept is present for all types of matters in Australia, and more generally in the Anglo-Saxon world. During interviews with oyster farmers in NSW, I have heard several times a willingness to show their commitment to and involvement for their community. Oyster farmers had partly this idea in mind while writing their EMSs: one the reasons for writing the EMS is to “demonstrate that oysters farmers are continually improving their environmental performance” (EMSWagonga, 2012, Introduction). By choosing transparency, over their activities and practices, they were willing to demonstrate that their activities are legitimate, clean, if not beneficial to the environment, ensuring positive externalities such as contributing to the image the region. Chapter 10 explores this question in more details.

In France, except one oyster farmer who kept evoking being part of a greater whole than the estuary, or organizing shore clean-ups, there was no mention of such a concept as community. Thau Lagoon oyster farmers seemed to rely more on their own families (during heavy workload periods such as Christmas) and on the State who is supposed to take care of issues such as microbiological peaks.

The Thau Lagoon is considered a single water unit as far as closures are concerned. In NSW, often, even in smaller estuaries than the Thau Lagoon, several zones are defined: some can be closed for harvest and others opened at the same time. I will develop this element and its consequences in Chapter 10.

8.4 Conclusion

In this chapter, I described in detail the two case studies that I investigated: the Thau Lagoon in France and several estuaries in NSW. Having explored several estuaries in NSW provides the advantage of not limiting the study to two cases which would be a path to simple comparison.

Both studies are located in developed countries, framed with numerous and relatively similar rules, especially those regarding oyster farming. Oyster farming already has a long history (longer than a person’s life) in both cases. Oyster farmers are dealing with a wide variety of institutions, either public, private or non governmental. They are both subject to specific rules on water quality leading to regular bans on sells.

I provide a comparison of the cases using the SES framework. This comparison revealed how close those cases were. Important differences exist in terms of information sharing and other types of interactions and thus outcomes. In NSW, EMSs have been developed by oyster farmers at estuary levels. Information sharing artifacts are less known and used in the Thau Lagoon case. Two main differences appear between the cases: size (less than 30 compared with 500) and the notion of community, more rooted in NSW. Projects such as collective implementation of information sharing artifacts is more difficult in

²⁰<http://www.thefreedictionary.com/community>

the Thau Lagoon since the number of actors is much higher (they are 15 times as numerous as in the estuary with the biggest number of oyster farmers in [NSW](#)).

Chapter 9

Goods and threats for oyster farmers

In this chapter, I use the theoretical elements developed in Part I to describe goods and threats in the context of the case studies. For their activity, oyster farmers have to deal with all types of goods and face threats of all types. One of the interests in studying oyster farmers is the fact that they work in an intrinsically open system. While most studies on the commons focus on relatively closed systems, the present work examines actors who have to deal primarily with a public good. Collectively, oyster farmers face two main threats: bacterial overflows that lead to sell bans and the herpes virus that decimates oysters. The virus is not yet well understood by science.

First, I detail the resources and goods oyster farmers use for their activities. Then, I show that Ostrom's CPR principles do not apply to this specific case study and thus do not easily extend to public resource management. Finally, I expose threats oyster farmers face and show that this angle is an adapted one to frame what farmers deal with to grow oysters. Information sharing solutions to the two main threats for oyster farmers are studied in Part IV.

9.1 Goods for oyster farmers

Oyster growers are part of a resource system that makes them use goods and resources that belong to all types of the goods typology (Table 2.1, p.13). CPRs are not at the core of the resources they use. Since the main resource used by oyster farmers is public (water, and more specifically water quality), this case provides an opportunity to try to apply Ostrom's design principles to see whether they would extend to public resources management (Table 2.4, p.17). The task proved difficult.

Table 9.1: Goods and resources for oyster farmers: a resource system.

† image can be considered a public good all can use or a CPR that is modified when used.

		<i>Subtractability</i>	
		<i>Low</i>	<i>High</i>
<i>Excludability</i>	<i>Low</i>	<i>Public good</i> Water quality, shore, estuary, genetic pool, image of oysters†	<i>Common-pool resource</i> Spat, phytoplankton
	<i>High</i>	<i>Club good</i> Lease areas, label	<i>Private good</i> Oysters, tables, oyster sheds, boats

9.1.1 Goods and resource system

Oyster farmers use and interact with goods of all types. Table 9.1 shows a selection of goods and resources that are of importance to them. As we have seen in Chapter 7, oyster farmers are heavily dependent on water quality which is a public good. Oysters (private good) are located on leases (private good limited in duration), that are located on estuaries (public waters or crown land in Australia). Access to lease areas is limited to professional oyster farmers and is thus a club good. They use their private boats to reach their leases. To process oysters, growers possess oyster sheds (private good) that are located on the shore of the estuary (public land, at least in France and NSW). In places where oyster farmers practice natural catchment of spat, spat can be considered a CPR. This method favors a diverse genetic pool (a public good). They are also collectively responsible for the public image of oysters by ensuring that consumers do not eat oysters that can make them ill, or even die.

Thus, for their daily activities, oyster farmers are entangled with all possible types of goods that are all of importance to them. They are fully part of a resource system with blurred boundaries (RS2) because of their heavy dependence on water quality. Cox et al. (2010) distinguish two parts within the clear boundaries principle (Table 2.4, p.17): actors (the type of users and property-rights are clearly defined) and resource (the resource used is easy to circumscribe). As discussed in Chapter 7, the size and limits of the SES, estuary or catchment, can be debated and argued resulting in a trade-off between being able to grasp a coherent group of actors and being able to internalize most (water) flows (Table 7.3). Drawing boundary lines is not an easy task in this case, and it is difficult to find a definitive and satisfying closure.

9.1.2 Common-pool resource principles

The necessary principles given by Ostrom for successful CPR management hardly apply to the context of oyster farming.

As repeated throughout this thesis, the main resource oyster growers deal with is water quality, a public good. It is strongly influenced by behavior and environmental dynamics that are external to oyster farmers' decisions. Ostrom's principles are applicable when users of the resource are those whose decisions influence (besides environmental dynamics) the state of the resource and its sustainability.

I use the formulation and codes of design principles given in Cox et al. (2010). In the previous section, I already discussed that boundaries are blurred (1), either for the actors (1A) or for the resource (1B) and that there is a trade-off between those two elements (Table 7.3, p.112). Congruence between appropriation and provision rules and local conditions (2) is only partly applicable. Appropriation should not be understood as in a classical CPR: oysters are grown on tables that are located on a piece of (flooded) land that is appropriated, similar to a farm land. From that point, interactions are rather limited. Local conditions are taken into account since some places of the estuary are more suitable for oyster growing than others. Collective-choice arrangements (3) exist (see the description of the case studies in Chapter 8) but can influence water quality mostly through efforts oriented towards actors who are not oyster farmers (Chapter 10). The same limitation applies to monitoring (4): there is limited internal monitoring (such as law suits to those who sail close to oyster leases or those who release brown waters directly in the estuary) since monitoring would be efficient mostly regarding actors who are not oyster farmers. Thefts are the most internal element that oyster farmers can monitor, sometimes with important consequences (ostracism) for the person who is caught (Figure 9.1). I have no specific information on graduated sanctions (5), except that the only information that I heard of was ostracism against a person who had been discovered guilty of theft. In this case, spraying the oyster farmer's shed was an efficient but rather brutal sanction, and a way to share the information that one should not steal oysters from others. Conflict-resolution mechanisms (6) exist within the local instances, in France and in NSW. Oyster farmers are recognized rights to organize (7). The emerging institutions deal with internal issues and research, set standards (especially in the case of NSW through the EMSs), and try to influence local political authorities to take their interests into account. In both France and NSW, there were nested enterprises (8), with several institutions trying to tackle issues at different levels.

The design principles have been developed with CPR management in mind, not public resources. The example of oyster farmers dealing with water quality clearly shows that they cannot easily be extended to public resource management. The major threat to CPR is exhaustion (or overexploitation) and those principles are designed with this threat in mind. The major threat linked to a



Figure 9.1: An oyster shed sprayed with “Go away bastard!” and “Thief!” on the shore of the Thau Lagoon.

public good is the absence of its provision, *i.e.*, the question of making sure that the resource is properly funded or maintained due to the possible presence of free-riders. In the case of water quality, what should be provided for is the absence of polluting inputs. In this situation, instead of using the lense of public good, it would be clearer to use the one of a public threat. Threats are a useful lens to frame questions related to oyster farming.

9.2 Threats for oyster farmers

In this section, I describe the main threats linked to oyster farming using the $\langle \mathcal{A}, \mathcal{C}, I, \mathcal{D}, \mathcal{E} \rangle$ formalism developed in Chapter 3. First, I give a general overview, then I go into more details to the two main threats: microbiological overflow and virus outbreaks. Microbiological prevision and mitigation is the core of the OMEGA Thau (Section 8.2.3.1) project and the virus is the problem most frequently cited by oyster farmers. These threats are those that are common to all estuaries where oysters are grown and are those that are considered the most severe and likely in EMSs risk matrices (cf. Figure 8.5, p.124). This explains the focus on these two threats.

Table 9.2: Threats of different types linked to oyster farming. Threats are inspired by the two case studies.

		<i>Internality</i>	
		<i>Low</i>	<i>High</i>
<i>Excludability</i>	<i>Low</i>	<i>Public</i> Microbiological peaks, algal blooms, sewage treatment plants	<i>Common</i> Virus transmission (common scenario), winter mortality, invasion of noxious oyster species
	<i>High</i>	X	<i>Private</i> Virus transmission (private scenario), sea bream

9.2.1 Microbiology

Microbiological peaks are one of the main threats to oyster farmers (\mathcal{A}) since they alter water quality (\mathcal{C}), leading to temporary closures. Run-off from upper catchment, malfunctioning of local water treatment plants, poorly adapted individual house treatment, cattle manure close to shorelines all lead to higher than acceptable microbiological rates or even peaks during heavy rains, putting at risk people who eat oysters.

Water quality is measured using *E. coli* levels in the water and oyster farmers are the most demanding users of estuaries regarding water quality (Section 7.1.3). Thus, oyster farmers have a strong interest in maintaining or at least favoring good maintenance, acceptable microbiological levels. Levels acceptable to harvest oysters guarantee water quality for all other uses.

Instead of proposing a classic public good provision problem, I propose to frame this element as a threat. In this case, maintaining water quality amounts to limiting global flows in the estuary. Thus, the question is not about providing a solution for water quality to be kept at acceptable levels, rather fostering and promoting practices (\mathcal{D}) and creating new infrastructure (\mathcal{I}) that allow water quality to maintain its current level.

For oyster farmers, the microbiological threat is non-internal and non-excludable: it is a public threat. The resource characteristic under threat is water quality and, as a consequence, access to the market (\mathcal{C}) (usually, microbiological peaks do not damage oysters but make them dangerous to eat; on the contrary, microbiological abundance favors a high growth rate). The threat depends on a combination of infrastructure, decisions and environmental dynamics. Related human infrastructure \mathcal{I} are water treatment plants, inappropriate house facilities, house boats, farms (through cattle and fertilizer). Decisions \mathcal{D} that directly impact water quality are those such as discharging black waters from boats in estuaries. Decisions \mathcal{D} to tackle the threat can range

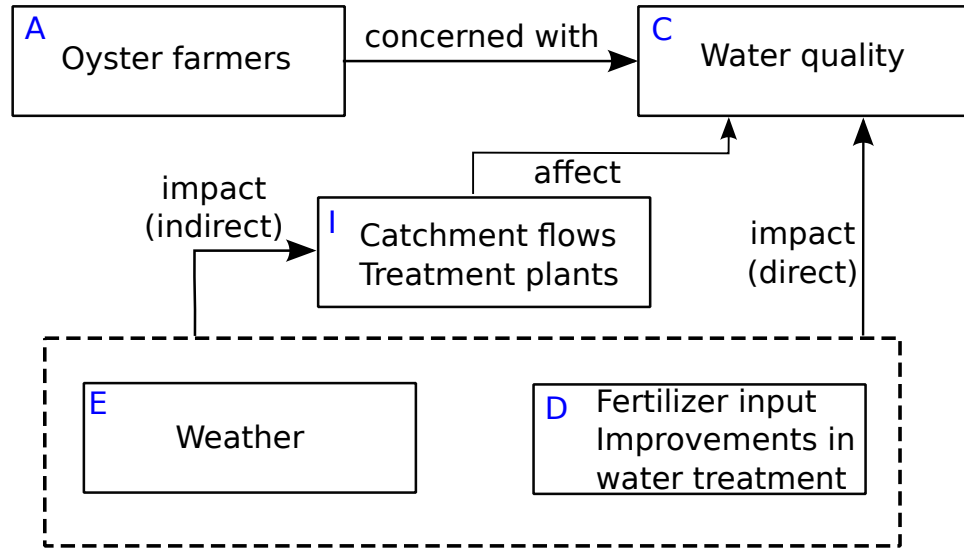


Figure 9.2: The microbiological threat.

from from upgrading treatment plants, enforcing rules on house water treatment, and investing in fences to prevent cattle manure from being too close to water. The main environmental dynamics **E** are linked to water flows, in the catchment and in aquifers, as well as the weather: heavy rains, especially after a long dry period, lead to important microbiological outbreaks. These examples are inspired from the French and Australian situations.

9.2.2 Virus

Oyster farmers (**A**) have been facing viruses that can kill up to 100 % of oysters. Viruses are threats to oysters lives (**C**). It is natural to define virus as threats.

Viruses have provoked crises for oyster farmers throughout history. A violent virus decimated the Portuguese oyster *Crassostrea angulata* in 1971-73 in France (Deltreil, 1973). This species had to be replaced by one which was more resistant, the **PO** (Grizel and Héral, 1991), which is now the primary species grown in France and around the world.

Oyster farmers in the Hawkesbury River, **NSW**, Australia have been wiped out because of a virus called the Qx (Queensland unknown) virus that killed up to 98% of **SRO** in 2004-5 (Butt and Raftos, 2007).

A virus, the OsHV-1 (ostreid) herpes virus, also called the **Pacific Oyster Mortality Syndrome (POMS)**, is currently wreaking havoc on the **PO** all around the world (Cameron and Crane, 2011). The virus has spread quickly around the world because oysters are moved several times during their lives. Moving oysters (**D**) has been prohibited between some estuaries in **NSW** to

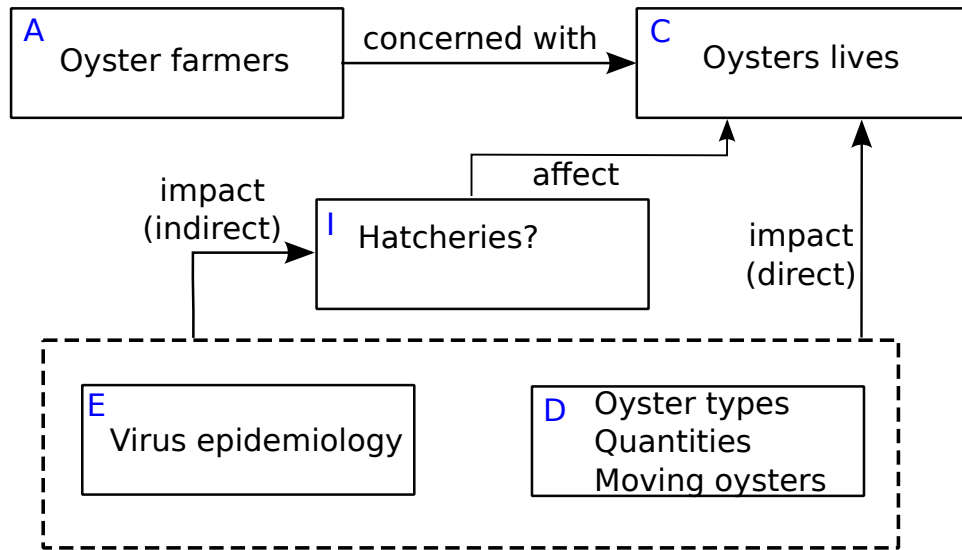


Figure 9.3: The virus threat.

limit this effect and prevent the spread of the virus to previously unaffected areas. The virus situation was evoked during interviews with oyster farmers as their most important problem.

The virus is worse than temporary sell bans due to microbiological issues since it kills oysters, while bans simply delay the moment in which oysters can be sold. This explains the lack of interest shown by interviewed Thau Lagoon oyster farmers regarding the OMEGA Thau project.

When temperatures rise in summer and the water temperature is between 17 and 24 degrees Celsius (Pernet et al., 2012), the virus becomes lethal (E) and within a few days, a massive amount of oysters, from 40 to 100 %, disappear (Oden et al., 2011). If the consequences are well-known (Girard and Pérez Agúndez, 2014), the virus *modus operandi* (E) is not yet understood (Paul-Pont et al., 2013). Pernet et al. (2012) or Whittington et al. (2015) point at oyster farming practices (D). Pernet et al. (2014) investigate energetic reserves and food quality (E). There is no consensus on how to cope with this threat and information is being gathered, models built, and results discussed (Cameron and Crane, 2011).

Oyster farmers also do not know how the virus acts but have several different representations of its *modus operandi* (E). During interviews, some oyster growers told me that the virus mostly touched triploid oysters, but this hypothesis has been proved untrue (Pernet et al., 2014), others blame hatcheries (I) that limit the genetic pool of oysters, favoring a high lethal rate. Some actors claim that they were not touched because they practice natural catchment (I, D) (the virus mostly kills spat and young oysters and those that are

caught are only those that survived according to them). Oyster farmers who have been severely hit and who decided to continue growing oysters were rather desperate about their situation. Finally, some oyster farmers worried about the quantity of oysters farmed in their estuary, saying that proximity and monoculture favored the expansion of the virus (D).

The virus threat is an internal threat. Even though there could be consequences on tourism and on the local economy, the threat impacts mostly oyster farmers. It is not clear whether the threat is excludable or not. Some oyster farmers said that they had no mortality due to their choices. Thus, it is possible to qualify the threat as private or common and make scenarios accordingly.

Using the categories given in the definition of threats, it is possible to say that the threat is characterized by ill-understood environmental dynamics and decisions of oyster farmers over the type of oysters they grow, and the quantity of oysters they decide to grow. Infrastructure contain hatcheries.

9.3 Conclusion

In this chapter, I have shown that oyster farmers use all types of resources and goods, the principal one being water (quality). Oyster farmers' situation does not fit Ostrom's [CPR](#) design principles well since they apply to resources subject to exhaustion in relatively closed systems, which is not the case of water quality. Water quality is subject to deterioration. Instead of framing this question using the public good provision framework usually proposed for public good management, I propose to use the threats framework which provides an easy-to-use model of a situation. The question is not about providing sufficient means for a public good to exist, rather favoring practices that limit the public good from being spoiled and polluted. Adding to microbiological threats, oyster growers are preoccupied about a virus that severely hits their oysters. This threat is an internal one which is not well understood. In this case, formulating the question as a threat rather than goods or resources seems more apt.

Threats provide a useful way to frame the major challenges oyster farmers face. Framing oyster farming challenges in this manner is easier to read and more intuitive than with the goods typology. Furthermore, filling the information necessary to describe thoroughly threats lead to discovering gaps in knowledge that need to be investigated and, as I will show in the following part, allows to look for proper solutions, possibly using information sharing, in the case of this thesis, and possibly through other means that I do not investigate here and reserve for future research.

Case studies - Conclusion

Oyster farming is particularly interesting and poorly studied in the research on collective management of goods and resources. The main resource farmers depend on is a public good, water quality, that is used by various types of users, and coming from areas farmers cannot control. Contrary to [CPRs](#) where issues come from insiders defection behavior, public goods such as these suffer from issues that are mostly external from oyster farmers' point of view.

Water in estuaries principally comes from the catchment area and the surrounding sea. Its quality is affected by direct users of the estuary and by nearby users: cities, farmers. Because of this fact, limits of the focal [SES](#) are unclear. Setting the boundary around the estuary leaves most of the main resource out of reach, while setting the boundary around the catchment leads to include a large number of actors of different types.

Oyster farmers are the most demanding actors in terms of water quality measured as a quantity of *E. coli* in the water. If water quality is good enough for oyster farming, then all uses are guaranteed. In that case sustainability, at least in terms of water quality, of practices of catchment actors can be demonstrated.

Investigating real cases with the goal of unveiling a [SES](#) calls for an interdisciplinary work. Different variables lead to various fields of study, in a fractal way. Each field opens up again as a vast combination of information, knowledge and complexity. Deciding when to stop digging is a non-trivial task. The very concept of emergence makes it difficult to know at which level of complexity and details to stop. In the thesis, I had to study and take into account the elements that seemed most essential to understand the cases. I made choices, and others could have been justified as well. Oyster farmers deal with oysters and a basic understanding of the biology and ecology of oysters is necessary to frame the general context. Oyster growers practices have to be described to grasp goals and constraints actors deal with everyday. One of the most relevant points consists in the fact that oyster farmers have limited leeway of action on the animals they grow: they cannot feed them, nor cure them.

I dug two cases. The first one is the Thau Lagoon, where 500 oyster growers farm around a single lagoon. The second one consists in several estuaries located along the [NSW](#) coast. Each of these estuaries are exploited by a much

smaller number of farmers (from 1 to 30). Practices are roughly similar. Both of these cases are located in stable democratic and developed countries where actors can express their voices and concerns. In both situations, actors have to deal with several (sometimes nested) institutions to deal with their activity. Due to the importance of water quality, these actors somehow have to raise their concerns using a way to share information. The results of this part of the situation are exposed in details in Part IV.

Information sharing in these cases is not organized in the same way. In the NSW case, the main artifacts, called *Environmental Management System (EMS)* are written and maintained by oyster farmers themselves. These open-to-all documents describe the catchment and estuary farmers act in, oyster farming activities and main regulations, as well as internal and external threats linked to oyster farming and how to deal with them. These documents are updated every two years and come with easy to read, accessible leaflets addressed to the main audience such as local dwellers and tourists. In the Thau Lagoon, the study focused on an information sharing artifact, OMEGA Thau, based on scientific modeling and sensory data developed by local public authorities in the hopes of predicting microbiological flows, in the short (due to weather conditions) and long (due to new constructions) terms. Oyster farmers can be warned earlier of temporary bans on sales risks.

Oyster farmers have to deal daily with all types of goods under different property regimes. They are fully part of a resource system, a resource system bigger than them because of the water quality element. Thanks to the example of oyster farming, I have shown that Ostrom's *CPR* design principles do not extend easily to actors who deal with a public resource.

Oyster farmers have to cope with two main threats. The first one is the target of the French information system: microbiology peaks that happen because of raining events and improper water treatment. This threat is a public threat that involves a large number of elements and processes. The second main threat, cited by most farmers that I interviewed, is the ostreid herpes virus OsHV-1 that is decimating *POs* around the world since 2004. This threat is an example of internal threat. Science does not yet fully understand how the virus works, or how husbandry practices influence lethality.

I investigated oyster farming and linked threats. What are the consequences on those threats for oyster farmers, oysters and water of the implementation of a new type of infrastructure: information sharing artifacts?

Part IV

Results



Results - Introduction

In Part III, I presented oyster farming in general (Chapter 7) and in the context of the specific case studies of the Thau Basin, France, and New South Wales (NSW), Australia (Chapter 8). In Chapter 9, I framed oyster farming stakes around two main threats: the microbiological one, linked to water quality; and the virus one, linked to oyster lives. The first threat is public, and the second internal.

In this part, I investigate consequences of on actors, on resources and mutual relations, of a decision D made by actors \mathcal{A} to implement a new type of infrastructure I , an information sharing artifact. The artifacts may contain information and may have an influence on any component of the $\langle \mathcal{A}, \mathcal{C}, I, D, E \rangle$ tuple.

Part IV is divided in two main chapters, each dealing with one of the two threats described previously. As shown in Chapter 4, stakes for information sharing for each type of threats are different. These two threat cases allow for an examination of those stakes through the study of a real context for the microbiological threat and using an agent-based model for the virus one.

In Chapter 10, I discuss how the implementation of Environmental Management Systems (EMSs) in NSW and OMEGA Thau made differences, or not, for the main categories of actors at all levels of the ENCORE framework in the public threat under scrutiny. I also show changes that these new infrastructures made in the Social-Ecological System (SES) and its perception by actors.

In Chapter 11, I expose the agent-based model that I developed and analyzed to understand what could be the consequences of implementing an information sharing artifact, in addition to existing social networks where information is exchanged, for actors business and oysters health.

Chapter 10

Information Sharing for Public Threats: Microbiology

In this chapter¹, I discuss how oyster farmers in the Thau Lagoon and in [NSW](#) are dealing with a specific public threat affecting oysters sells: the microbiological threat. Different strategies have been implemented in those places. As explained in Part [III](#), the microbiological threat is disturbing directly oyster farmers mostly as a result of activities impacting water in the catchment surrounding the estuary where oysters are grown.

As exposed in Figure [9.2](#), p.148, the microbiological threat is framed in the following manner: oyster farmers constitute \mathcal{A} . Oyster farmers are worried about water quality (\mathcal{C}). \mathcal{C} is affected by catchment water flows, by local treatment plants or private houses, or by fences around farms close to the shore (\mathcal{I}). Decisions \mathcal{D} that affect \mathcal{C} include improvements in water treatment (indirect), or house boat pouring black waters in the estuary (direct). Microbiological peaks are due to heavy rain events or particular weather conditions (\mathcal{E}). To oyster growers, this threat is non internal. In France, and in several estuaries in Australia, sale bans affect whole estuaries and growers cannot individually exclude themselves from the threat (except if they grow oysters in another estuary). Thus, the microbiological threat is a public threat for oyster farmers. How can information sharing help?

I explore strategies that have been developed by actors of the case studies with the lense of information sharing artifacts. I mostly draw upon [EMSs](#) for the [NSW](#) case and upon OMEGA Thau for the French case. [EMSs](#) are documents written by farmers, dealing with numerous questions, including the microbiological one, and OMEGA Thau is developed by local public authorities and is mostly focused on following water and microbiological flows. How do these artifacts make the [SES](#) evolve? What is the effect of these strategies on the resource and the actors?

¹This chapter is adapted from [Paget et al. \(2016\)](#), a paper published in *Natural Resources Forum* analyzing the [NSW](#) case. The whole paper is reproduced in Appendix [C](#).

First, I give consequences of implementing EMSs for oyster farmers in NSW, using the ENCORE framework (Section 4.4) as well as evolutions in the SES. Then, I study the French case using the same frameworks. Finally, I draw conclusions that can be learned from those cases.

10.1 Dealing with microbiological threat in NSW

Actors managed to collectively create information sharing artifacts, EMSs, that led to increase their legitimacy over water quality management, enabling stewardship over water. This example is a positive case of downstream actors empowerment in a case of public threat. I show this transition by using an adaptation of the ENCORE framework and the SES one.

10.1.1 Legitimization of stewardship over water management

In NSW, internal changes in information sharing, through the creation of *Oyster Industry Sustainable Aquaculture Strategy (OISAS)* and more importantly EMSs, played a part in legitimizing the role of oyster farmers as stewards over water (quality) management.

EMSs are described in Section 8.1.3.2, p.123. They are composed of three main elements. The main document, detailed, specific and containing a description of all risks. The second one is a leaflet intended for a broad audience. The last one is an update in which farmers fill indicators to track evolution of risks. Figure 10.1 shows how EMSs are linked to the microbiological threat.

To ensure good water quality, oyster farmers have to cope with other actors' actions, and have to deal with upstream catchment users and processes (*i.e.* external risks in the EMS terminology, public threats using the threat typology). There were also misunderstandings throughout the community regarding oyster farmers' impacts on the estuary and on the legitimacy of crown land use. EMSs development allowed the community to learn about typical industry practices and roles as stewards of good water quality. EMSs are information-laden documents. Table 10.1 shows their impacts on different populations using the ENCORE framework.

In this case, I use ENCORE to evaluate how implementing artifacts (here EMSs) can make different types of actors evolve on the subject of the microbiological threat, and water quality, on ENCORE dimensions. All changes listed in the table did not occur in all estuaries where EMSs have been developed. EMSs have different roles as interface across actor boundaries. They enable oyster farmers to state an official and argued position which can be efficiently communicated when necessary. They are information artifacts that allow communication between different categories of actors. According to Gietzelt et al. (2014, p.2):

When South East Local Land Services first engaged with the

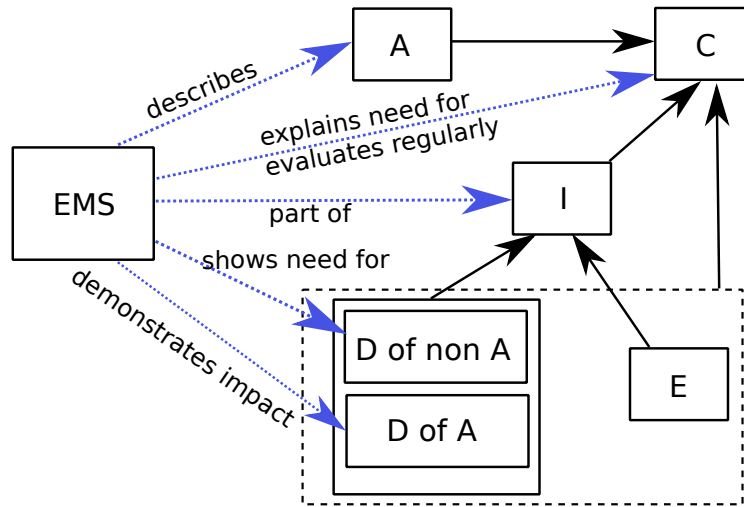


Figure 10.1: Information regarding (microbiological) threat included in an EMS. About D: \mathcal{A} contains oyster farmers; non \mathcal{A} contains other actors such as government and councils, farmers ... Differences made by the artifact for these actors are detailed in Table 10.1. See also Figure 9.2, p.148, to get a description of the microbiological threat using the threats formalism.

oyster industry in 2003, [oyster farmers] were frustrated with their lack of influence over processes and practices threatening their industry. When issues [...] caused the temporary closure of oyster harvesting, their response was generally reactionary, and they did not have a loud and collective voice when expressing their concerns to government and the community.

Gietzelt et al. (2014) explain how local councils and the oyster industry worked hand in hand to develop EMSs and address issues raised, to the point of creating an ongoing Oyster Partnership Program in 2006. This Program partly subsidizes a position of EMS implementation officer and promotes oyster performance monitoring programs (RS7, I9, O2) among other actions. Furthermore, upon submission of a development application to a Council, consequences on water quality are to be considered and oyster farmer representatives consulted in case of possible impact (I10, O2) (OISAS, 2014).

Table 10.1 shows how these documents make differences in all dimensions of the ENCORE framework. Globally, due to evolution of normative and cognitive mindsets, actors who produced negative externalities (high microbiological flows) are more prone to make decisions and adopt practices (operational and external dimensions) that take water quality into account. By publicly showing their personal efforts, oyster farmers managed to smooth relations with other stakeholders and improve the equity feeling.

Table 10.1: Possible evolution of actors according to ENCORE dimensions if an EMS is implemented. I listed potential effects on parts of the microbiological threat.

[†] OF = Oyster farmer(s).

Dim	Differences generated by of EMS implementation	
External	OF [†]	Cleaning up of derelict and polluting infrastructure, investment in sustainable infrastructure (<i>I, D</i>)
	Govt and councils	Can use oyster farmers knowledge and presence to assist when monitoring
	Farmers	Fencing off cattle to limit access to the estuarine foreshore (<i>I</i>), regrowth of riparian vegetation (<i>I</i>)
	House owners	Better on-site sewage system (<i>I</i>)
	Community	Safety during swimming and recreational fishing (<i>C</i>)
Normative	OF	OF should provide stewardship over water, others should be made aware of their impacts
	Govt and councils	OF should provide help as stewards of the waterways
	Farmers	Need to play a role in keeping good water quality
	House owners and community	Should be made aware that they can have an impact on water quality
Cognitive	OF	Government is not an enemy
	Govt and councils	Oysters are good indicators of estuarine health
	Farmers	Farming activities can impact water quality (<i>D</i>)
	House owners	Micro behaviors can affect the whole system (<i>D</i>)
	Community	Aware that OF are not harmful (if not beneficial) to the environment, OF is associated with clean environment, suitable for tourism, generating income for the local economy
Operational	OF	Reducing high internal threats by implementing threat mitigation procedures (<i>I, D</i>)
	Govt and councils	OF are integrated in decision processes (<i>I, D</i>)
	Farmers	Maintain cattle out of the water, behind fences (<i>I</i>)
	House owners	Improve or maintain sewage treatment (<i>I, D</i>)
Relational	OF	Legitimate members of the community, can talk to others with pride
	Govt and councils	OF are knowledgeable partners
	Farmers	OF are partners in environment quality
	House owners	Accept better OF requests for costly improvements
	Community	Common interest in tourism
Equity	OF	Feel that they have input
	Govt and councils	Better acceptance of decisions
	Farmers and house owners	Agree to invest knowing OF make efforts
	Community	Legitimate use of crown resource

10.1.2 Evaluation of consequences on the SES

The identification of boundaries and content of the SES by its actors has dramatically changed with the creation of these documents. [EMSs](#) are new resources available to oyster farmers to act on an object of core importance to them: water quality and the estuary in general. As shown before, they are used in many different ways: during development application processes; for raising awareness; to allow farmers to voice their views; and for interacting with council. [OISAS](#) is another government-owned resource that can be used in similar cases to ensure optimal water quality. The [SES](#) framework analysis shows (Table 10.2) that these new resources have had an effect on a considerable number of variables of the [SES](#). One of the most important is that it allowed the size of the system (RS2) for the oyster farmers to be redefined in a tangible manner. Instead of being focused and constraining actions to the estuary limit, the system now includes the whole catchment and the processes that could indirectly affect oyster farming practices. This had an impact on pollution patterns (ECO2) and flows into and out of focal SES (ECO3): pollution events are now internal, and thus can more easily be addressed and flows in and out are reduced because the system is defined at the catchment level, which prevents water from entering from other systems, except from the sea. This could happen thanks to the definition of new rules at all levels: constitutional, collective and operational (GS*). These rules have affected information sharing, self-organizing, monitoring, networking and evaluative activities. They even defined social and ecological performance measures that will allow efficient monitoring of outcomes. Figure 10.3 shows the evolution of oyster farmers' representation of the system (A7).

Table 10.2 has a column called “transition”. This column gives the means that led to the change of perspectives given in the table as well as those of the ENCORE dimensions (Table 10.1). One of the main elements that allowed this transition is the very process of collectively building the document. Elements such as “meetings” are core in the transition process: they force actors to think through their own activities, elements linked to their activities, and lead to a collective discussion and then stabilization (in the artifact) of topics.

10.1.3 Partial conclusion

[NSW](#) oyster growers have managed to create documents that are highly respected by public authorities and other stakeholders (cf. [Gietzelt et al., 2014](#)), that legitimated their use of a public resource and their role as stewards of water in the eyes of different stakeholders.

Actors are thus empowered through the implementation of this artifact. These documents are information-laden in the sense that they make differences in the eye of multiple stakeholders, including oyster farmers themselves. In that case (see Section 10.3), information sharing artifacts existence lead to a

Table 10.2: Evaluation of consequences of the implementation of the environmental information sharing system on a selection of the SES variables (Section 2.3).

Variable	Initial features	Transition	Features after implementation
RS3 - Size of RS	Estuary	Effective internalization of issues	Catchment
RS7 - Predictability of system dynamics	Difficult	Indicators multiplied	More precise (<i>e.g.</i> growth and mortality)
GS2 - Non government organization	Only compulsory local ones	Emerged through meetings	SWCO, AOC
GS3 - Network structure	Porous	Meetings	Very dense, at least at the estuary level
A6a - Trust / Reciprocity	Little	Meetings	Improved, for environment at least
A7 - Knowledge of SES / Mental models	Upstream actors responsible	Holistic view	Part of a catchment
A9 - Technology available	Any	Long-term thinking while elaborating	Sustainable, non polluting at least internally
I2 - Information sharing	Little	Forced through meetings on consensual subjects	Among actors, with others
I3 - Deliberation process	Meetings for water quality	Canalized through meetings	Regular meetings at several levels
I5 - Investment activities	Water and meat monitoring	Identified through meetings	New technologies (individually), clean-up
I6 - Lobbying activities	Dispersed	Made easier with hard documents	More centralized
I8 - Networking activities	Dispersed	Hard documents exist, EMS officer	More systematic (incl. in government processes)
I9 - Monitoring activities	Point localized monitoring	Government implicated	Extensive, partnership with government for stewardship, growth and mortality
I10 - Evaluative activities	Little	Range of indicators defined	Extensive
O1 - Social measures	Little	Deep thinking about sustainability	Sustainability is core
O2 - Ecological performance measures	Little	Deep thinking about sustainability	Precisely defined
ECO2 - Pollution patterns	Many, upstream, dispersed	Scale change	Now effectively internal and more reachable
ECO3 - Flows into and out of focal SES	Flow from catchment	Scale change	Now internal and more reachable

closure of the upstream downstream system through an information flow.

The [NSW](#) case is an example of downstream actors who develop information sharing artifacts that make a difference as much for them as for other formerly unreachable upstream actors who impacted a resource used by those downstream actors. Public authorities welcomed this initiative by sponsoring a process for which both parties have aligned interests: both categories of stakeholders wish to maintain good water quality, to keep the employment rate, to sell oysters and to develop an attractive region. Consequences of this implementation are praised by actors, by public authorities, but the direct impact on water is difficult to measure (interview with [NSW](#) food authority, November 2014): many factors apart from the artifact implementation may impact water quality; changes in practices may have been adopted without the existence of the artifact. Despite the absence of measurable consequences, impacts of the process are multiple, and mostly positive, as shown by the [ENCORE](#) framework and transitions seen in [SES](#) mental model.

10.2 Dealing with microbiological threat in Thau

In the Thau Lagoon, the main artifact implemented oriented towards the microbiological threat is [OMEGA Thau](#), a system developed by local public authorities and scientists that models and monitors water flows in the catchment. As a spin-off, water quality information destined to oyster farmers, swimmers and recreational boaters are transmitted. Information on potential imminent sale bans is provided in timely fashion to oyster farmers, so that they are able to take measures to prepare the ban and continue selling oysters.

10.2.1 A difference that makes a difference?

Thau Lagoon oyster farmers are subject to the same microbiological issues as [NSW](#) growers. Yet, the artifact that has been developed has different consequences on the system. The [ENCORE](#) framework is appropriate to analyze those consequences (Table 10.3). I chose the same type of stakeholders as in the previous section, except for house owners that I replaced by project sponsors, stakeholders for whom the impact of the existence of this model is more relevant.

Consequences for oyster farmers are limited in the short run, but may be more substantial in the long term. As a reminder, traditional small scale activities (“petits métiers” ([Giovannoni, 1995](#); [Sécolier, 2009](#))) are placed at the heart of local development schemes of this catchment (cf. [SAGE-Thau, 2015](#)) and are well represented in local instances, especially during the participation phase dedicated to develop those schemes ([SMBT, 2012](#)). Legitimacy of oyster farmers and fishermen, at least in the eye of public authorities, over the use of the resource is granted and demonstrated through these documents.

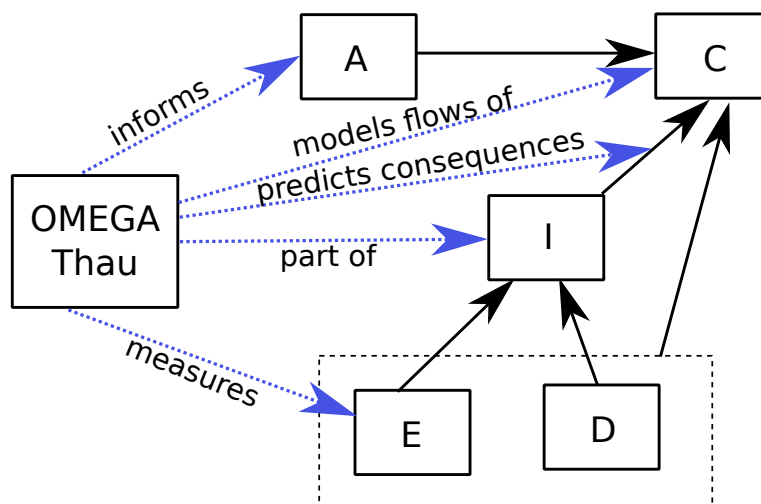


Figure 10.2: Information regarding microbiological threats included in OMEGA Thau.

OMEGA Thau in itself has limited consequences for oyster farmers on the short run since predictions are heavily dependent on weather forecast and growers know that heavy rains usually have sale bans as a result. Their depuration basins are constrained in size and are usually too small to be able to store more than a few days worth of oysters.

Interviews have revealed that grassroots farmers were not aware of the existence of the OMEGA Thau project (despite meetings organized by the [Syndicat Mixte du Bassin de Thau \(SMBT\)](#)), even after several years of development. Adding to this fact, most farmers told me that having information a little earlier would not significantly change their practices for the reason stated above. According to an oyster farmer interviewed in April 2014: “We will never get information more accurate than the weather forecast. [...] If we are informed that it is going to rain, we stock oysters in our depuration basins. No need for big models”. This element allows to conclude that the difference created by the existence of OMEGA Thau does not make much difference for oyster farmers and can thus be considered as non-information.

On the long run, the situation is different. This model provides accurate predictions of consequences on water flows of new developments. Sponsors have to integrate this element to propose projects. Water quality on the long run can be mastered with more precision than before. Water quality, measured in terms of days of bans on sales have been improving steadily during the last decade as shown by Table 8.2, p.130.

Despite possibly limited direct effects on oyster farmers, the implementation of this artifact will probably lead to improvements of water quality management in the catchment. It is necessary to mention that this artifact

Table 10.3: Possible evolution of stakeholders according to ENCORE dimensions if OMEGA Thau is known by stakeholders.

[†] OF = Oyster farmer(s); [‡] WQ = Water quality.

Dim	Differences generated by OMEGA Thau implementation	
External	OF [†]	Almost no effect on the short run; Improvements in knoweldge and impacts on WQ [‡]
	Govt and councils	Can use system to monitor water flows and predict WQ for developments (<i>I, D</i>)
	Farmers	None
	Project sponsors	Need to take WQ into account (<i>I, D</i>)
	Community	Safety during swimming and recreational fishing (<i>C</i>)
Normative	OF	Authorities are responsible for WQ management
	Govt and councils	Public authorities should take care of WQ
	Farmers	None
	Project sponsors	Should pay attention to consequences on WQ
	Community	None
Cognitive	OF	Public authorities do what they can to guarantee WQ
	Govt and councils	Can master future developments projects impacts and understand water flows
	Farmers	None
	Project sponsors	Individual projects have global consequences (<i>I, D</i>)
	Community	Water quality is an important issue
Operational	OF	Limited (warning a little earlier) (<i>D</i>)
	Govt and councils	Possess a decision aid tool to predict consequences of new developments (<i>I, D</i>)
	Farmers	None
	Project sponsors	Need to pass model test (under admissible levels)
Relational	OF	Good relations with public authorities
	Govt and councils	Are legitimate monitors of WQ
	Farmers	None
	Project sponsors	May feel more constrained
	Community	Good image of local authorities
Equity	OF	Feel that their resource is managed correctly
	Govt and councils	Better acceptance of decisions
	Farmers	None
	Project sponsors	Unknown
	Community	Unknown

is not the only means through which local authorities are improving water quality and water management in the whole basin. Participation of actors in drafting documents (information coming from n people to an institution I as proposed in Table 4.4, p.55) is a central element of their schemes creation strategy. Moreover, deals with localities and messages to the general public (from I to n) promote a lower use of biocides².

Interviews have shown that there is little solidarity among oyster farmers in normal conditions (“we are kind of single people”). They compete on prices, no coalition has ever resisted to free-riding temptations. However, oyster growers have a sense of community when a decision is deemed unfair, for instance long sell bans due to localized events. In those cases, farmers may join their forces to obtain a reconsiderations on bans.

10.2.2 Partial conclusion

In the Thau Basin case, the information sharing artifact is mostly a technical tool that is little known by actors (though solid on the modeling side). Effects of its implementation are limited to increasing knowledge on water flows (which is the goal of the artifact). Percolation effects are much more limited than in NSW (see Table 10.3).

However, water quality is improving, projects are better mastered and constrained. The information sharing artifact is here not the central element of the global strategy for resource management. It is only one of many strategies deployed by local authorities, and oyster farmers are already legitimate users of the resource. They are consulted when strategies are implemented.

In Table 10.2, I have shown differences made on actors’ mental models in NSW due to EMS implementation. Most transitions are linked to the creation process and not to information itself. In Thau, differences made by OMEGA Thau on the SES are negligible since the artifact improves direct scientific knowledge unlike the global process that led to changes in the NSW case. There were no global meetings with oyster farmers that allowed discussion and changes in perception of the SES. Thus, I did not create a table as for the NSW case.

The number of oyster farmers in the Thau Lagoon makes a collective implementation of these projects difficult. There is a representation of farmers interests through their official lobby, the [Comité Régional de la Conchyliculture de Méditerranée \(CRCM\)](#) public authorities communicate with. Furthermore, public authorities are seen as responsible for water management.

Table 10.4: Comparison of IS artifacts - what information do they provide?

Artifact	<i>C</i>	<i>I</i>	<i>D</i>	<i>E</i>
EMS	General	Assessment	Aggregation; Consequences	
OMEGA Thau	Microbiological flows	Prediction	Projects	Measures

10.3 Discussing strategies

A question of scope Let me recall the main sub question of the thesis tackled in this chapter: what are the consequences of information sharing artifacts' implementation and existence to face a public threat, specifically the microbiological threat?

In both cases, information sharing artifacts have been implemented. In [NSW](#), the artifact originates from the oyster farming industry, while in Thau, the artifacts emanates from public authorities. In both cases, the artifacts gather information regarding the microbiological threat (Table 10.4), even though EMSs are wider. One is updated every day using weather forecast and multiple sensors, the other is updated every two years, using aggregated information gathered along the years.

In [NSW](#), actors have created an artifact which consequences go far beyond a mere deepening of knowledge since it had consequences on their own solidarity and network, had tightening effects with other stakeholders, including local authorities as shown using the ENCORE framework (Table 10.1). They managed to close a loop, evoked in Section 2.2.3, p.18 and Figure 2.1, p.19, using information as feedback and making allies of local authorities. Changes are shown in Figure 10.3. EMSs can be used as a communication tool between oyster farmers and upstream actors, even without local councils intervention.

Figure 10.4 shows that the information sharing artifact OMEGA Thau is connected only to regulators and local councils, not touching (originating from or going to) other stakeholders. Local authorities are institutions that are boundaries between local actors and the environment, which goes hand in hand with local economics due to the high economic value of the environment.

Direct measures of impact of information sharing artifacts are difficult to evaluate. First, those artifacts are quite recent and effects of measures and practices triggered by the existence of these artifacts are not immediate. Second, some practices, improvements or developments are independent from the existence of the artifacts and yet have an effect on water quality.

²<http://www.smbt.fr/content/lutte-contre-les-pesticides>

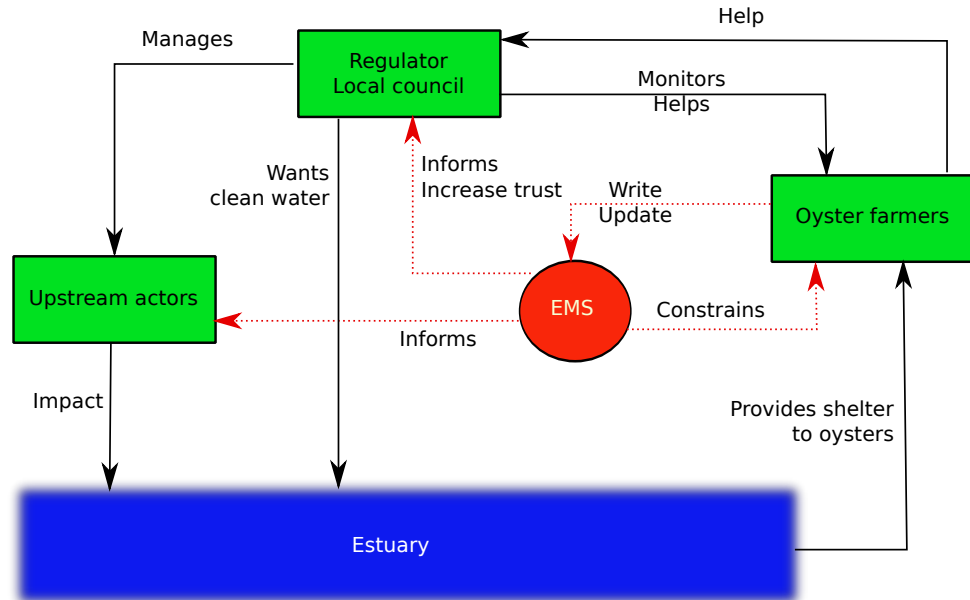


Figure 10.3: Consequences of EMS implementation. In dotted red, links that did not exist before the implementation.

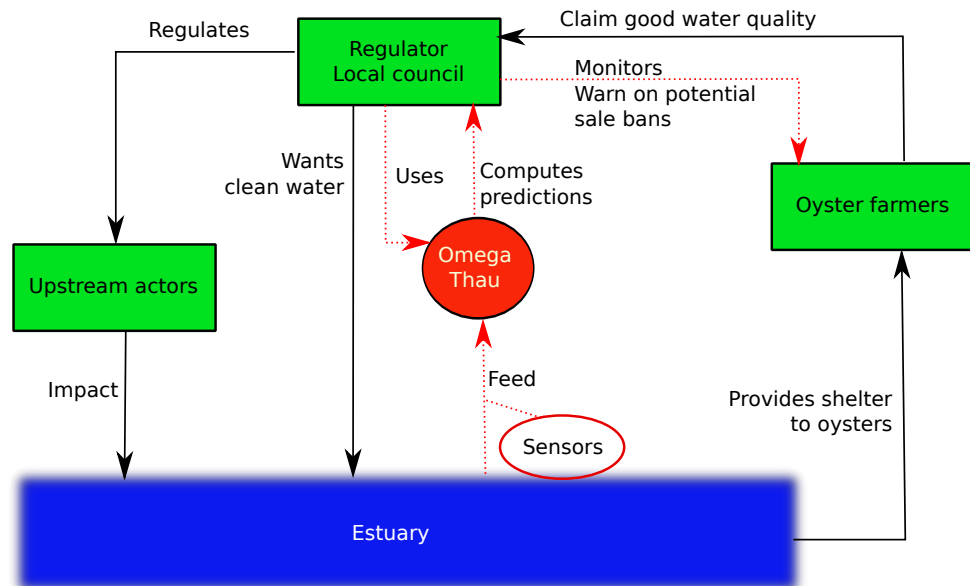


Figure 10.4: Consequences of OMEGA Thau implementation. In dotted red, links that did not exist before the implementation.

How to convince actors? According to OceanWatch facilitator, success in implementation of an industry-emergent artifact is fundamentally linked to the creation and appropriation process. In NSW estuaries, there are a limited number of oyster farmers, ranging from 10 to 30, making meetings with all actors possible. Initially, a few proactive farmers decided to create EMSs for their farm, realizing soon that their leeway was limited due to the openness of the system they act in. In their own estuaries, proactive farmers managed to convince the other oyster farmers, backed by OceanWatch who is a legitimate organization for actors in the seafood industry, interfacing public authorities and industry.

The first estuary-wide EMSs began this way. After the first example, and advocated both by OceanWatch, drawing on previous success, and by professional farmers, the process became increasingly clear: OceanWatch facilitator manages to find the local champion, the actor who is respected and listened to by others, convinces him of the importance and outcomes of implementing an EMS and finally the process, a series of meetings, begins.

Actors that I interviewed in France complained about the lack of interactions with others, about their individualism and about a lack of cohesion or even a sense of community. Projects such as implementation of an EMS, emerging from meetings among actors and not created by an intern doing research in a laboratory, may be of help to make the dimensions listed in the ENCORE framework converge towards more cohesion for various types of actors. Implementing such an artifact may be a possible way to go beyond the listed frustrations.

In the Thau Lagoon, there are more than 500 sheds. It is thus impossible to organize meetings with everyone and ask about their opinions. Sheds are located along the shore in patches. Those patches contain a more reasonable number of actors. A similar process as the Australian one may then be launched. As explained above, this strategy needs to be carefully planned, introduced by local, influential, and respected actors who are convinced of the interest of such a process. Since oyster farmers possess a local lobby that is supposed to be in charge of collective issues, the project may originate from there. When I came back to France to present findings on the Australian case, the lobby proved interested in the existence of such a document. Water quality issues are overseen at the catchment level by local public authorities and oyster farming and fishing are located at the center of local development schemes. Implementing such EMSs would probably mostly make oyster farmers' mental model involve, through the generation of discussions, more than have direct effects on water quality.

These observations show the importance of the creation process which has to be carefully thought in advance so that actors accept the idea of going through such a lengthy route.

10.4 Conclusion

To face a public threat, in our case microbiological overflows threatening water quality, information sharing is thus a possible and effective option.

In the Thau Lagoon, the artifact has demanded considerable research and consolidation work. The result is a neat tool that can mostly be used to predict water flows (and soon consequences of floods) for a few days and model outcomes of new developments regarding water quality. Using the ENCORE framework (Table 10.3), I have shown that consequences of this information sharing artifact are mostly limited to the intended initial goal: to monitor and predict flows. The system and actors not directly concerned with the artifact were only partly affected.

In NSW, farmers who developed “estuary-wide” EMSs together, managed to create collateral beneficial effects for themselves and with others types of actors of their surroundings, including the rather abstract “community”, as shown in the ENCORE table (Table 10.1). One of the main of these effects is legitimization of their role as stewards, and even sentinels, over water, specifically water quality. This case enables to emphasize the importance of the creation process of artifacts.

Furthermore, the NSW case shows an example of downstream actors, who have to suffer upstream actors externalities and managed to create a feedback flow of information from downstream to upstream. This action paved the way to an effective change in practices and relations between those actors, with the help of public authorities. Information sharing through the creation of an artifact, an external representation, is here a way to effectively change the scale of how actors perceive the system they act in. Information sharing is here a way to strengthen links between actors of the same profession and create or improve links with other types of actors.

Chapter 11

Information Sharing for Private Threats: Virus

In this chapter, I focus on a threat that oyster farmers growing [Pacific Oyster *Crassostrea Gigass* \(POs\)](#) around the world experience: the ostreid herpes virus OsHV-1, that can kill up to 100% of oysters. To oyster farmers, this threat is internal since the only users affected are oyster farmers. It is not clear however if it is excludable or not: is it linked to the collective behavior (the macrobehavior) of oyster farmers or linked to individual practices independently from each other?

Three elements prompted me to create an agent-based model to study information sharing contribution in the virus context. Firstly, OsHV-1 has been evoked regularly by oyster farmers I interviewed as the main issue they currently have to face. Secondly, [Nash and Rubio-Zuazo \(2012\)](#) have developed an information sharing system as a proof of concept (according to the authors) called the *Oyster Information Portal* that would combine information about quantities, mortalities and growing rates so that oyster farmers could acquire knowledge and adapt. Oyster farmers proved interested in the concept. Thirdly, tracking participation and outcomes of information on the long run is an impossible task: situations are not reproducible and other factors have influences. [Agent-Based Modeling \(ABM\)](#) offers the opportunity of tracking and reproducing those elements.

It is not sure how excludable the virus threat is and several scenarios can be considered. Since the focus of the thesis is on information sharing consequences, I decided to build a model where interactions are placed at the information sharing level only, with a goal of collective learning on the virus dynamics leading to individual decision-making. I took the option of designing the threat as a private threat where the virus acts at the batch level independently.

In this chapter, first, I use the [Overview, Design concepts, and Details \(ODD\)+D](#) protocol (Section 6.4.1.3, p.91, see also [Grimm et al. \(2013\)](#); [Müller et al. \(2013\)](#)) to describe the model. Second, I analyze simulation outcomes.

11.1 Agent-based model description

In this section, I describe the agent-based model that I developed to investigate how information sharing can influence actors and the resource they produce. I follow the ODD+D protocol (Grimm et al., 2013; Müller et al., 2013) by answering to the listed questions in the cited papers (the table containing all questions is reproduced in Table A.1, p.256).

11.1.1 Overview

Purpose What effects can information sharing have on adaptive management of a renewable natural resource used by some actors in the context of an internal threat, *i.e.* the herpes virus? As postulated in Chapter 4, for this type of threat, the main goal of sharing information is for agents to learn environmental dynamics. Does information sharing increase their knowledge of the resource and its dynamics? Can it lead to better outcomes for the environment and for the agents? Does implementing an information sharing system help oyster farmers to adapt to this virus they do not fully understand?

This ABM is designed as an exploratory one. It is not conceived as an operational and predictive decision aid model that could be used by local actors.

Entities, state variables and scales There are three main classes of entities in the model: `OysterFarmer`, `Oyster` and `WaterCell`. Figure 11.1 shows the main classes of the model using an UML class diagram.

OysterFarmer They are cognitive agents. Based on interviews and following an oyster farmer suggestion, I designed three main behaviors (**type**) in the set {`economicus`, `conservative`, `conscious`}. I describe the behavior of these classes of agents in the “Individual prediction” structural element.

Oyster `PO` are the only oyster species considered. Three types of `PO` can be grown. The `Natural`, an oyster that has to be caught in the wild, only in summer. The other two are *Hatchery* oysters: `Triploid` and `Diploid`. Triploids grow in 6 trimesters, while diploids and naturals grow in 12. Both kinds of hatchery oysters can be ordered all year long. All oysters are considered in batches containing up to 10,000 oysters. These batches are placed on tables. More information on oysters biology and ecology can be found in Section 7.2, p.105.

WaterCell This is the spacial entity. Viral elements are located in the water and regularly kill oysters. Mortality is an increasing function of oyster quantity and density (see Section 9.2.2, p.148 for a discussion). I designed three virus dynamics scenarios including a null one (Figures 11.2

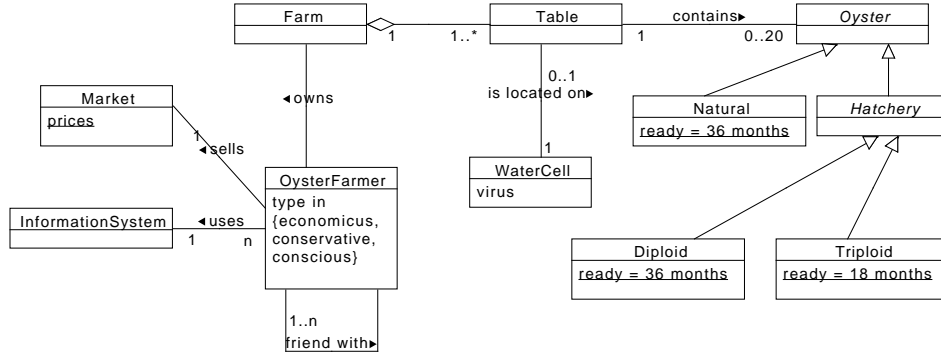


Figure 11.1: UML class diagram representing the ABM main classes.

and 11.3 show virus scenarios and consequences on oyster farmers expected income). I chose a simple virus model presented in Gilligan (2002) to see impacts of information sharing in these scenarios. The virus hits depending on quantity of oysters located on a table only. I chose to assign to the virus a sigmoid function of oyster quantity q : $f(q) = \frac{K}{1+a \cdot e^{-rq}}$ defined for $q \geq 0$ where a is a parameter that allows changing the sigmoid mid-point abscissa, r a parameter that modifies the curve steepness and K is the maximum of the function. Thus, a virus scenario is defined by three triplets, $S = \langle S_n, S_d, S_t \rangle$ where $S_i = \langle a_i, r_i, K_i \rangle$, allowing the parametrization of the sigmoid function for each of the three types of oysters.

Three scenarios are considered:

- The first scenario, no mortality, is the reference scenario, used as a base for comparison.
- In the second scenario, there is a virus that hits oysters. The virus is the simplest to understand and designed so that mortality curves never overlap: $\forall q \in]0; 10,000], M_t(q) > M_d(q) > M_n(q)$.
- The third scenario is close to the second one. In this case, curves overlap at some point. Triploids end up being those with the highest mortality rate when quantities reach a specific point.

Process overview and scheduling Figure 11.4 shows the relations that the agents have with the environment and the information sharing system through the main loop. An agent observes outcomes of her practices in her oyster farm. She shares information through her network and the information sharing

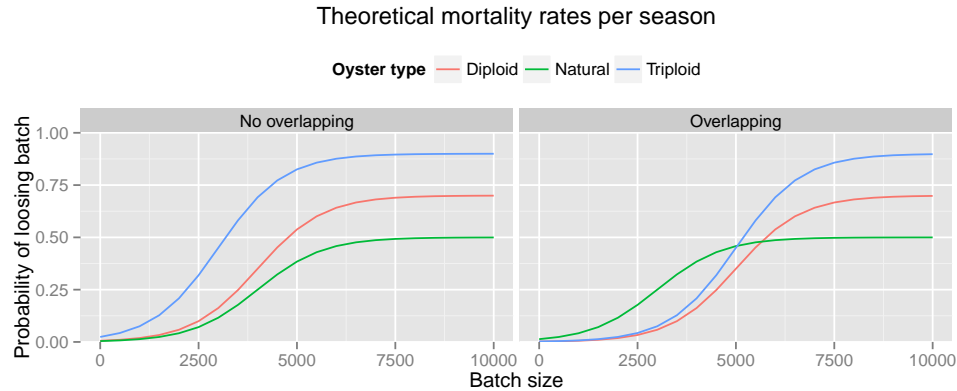


Figure 11.2: Annual mortality as a function of oyster quantity for the two scenarios with virus mortality.

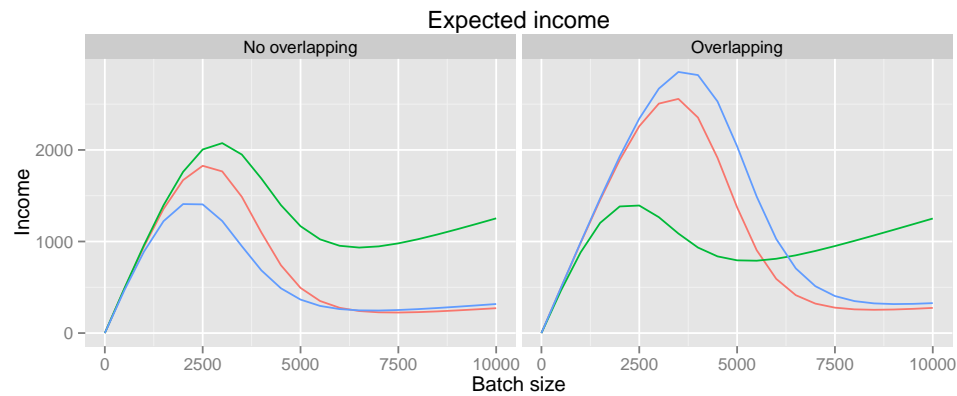


Figure 11.3: Theoretical expected income along oyster quantities taking into account oysters growing cycle length. In the “no overlapping” scenario, natural oysters give better income whatever the chosen quantity. Whatever the quantity, for a given oyster type, the maximal income is obtained around 2,500 and 3,000 oysters per batch. In the “overlapping” scenario, hatchery oysters are the best option, with little difference between triploids and diploids. If oyster farmers choose batch sizes over 6,000 oysters, the best economic option is to choose natural oysters.

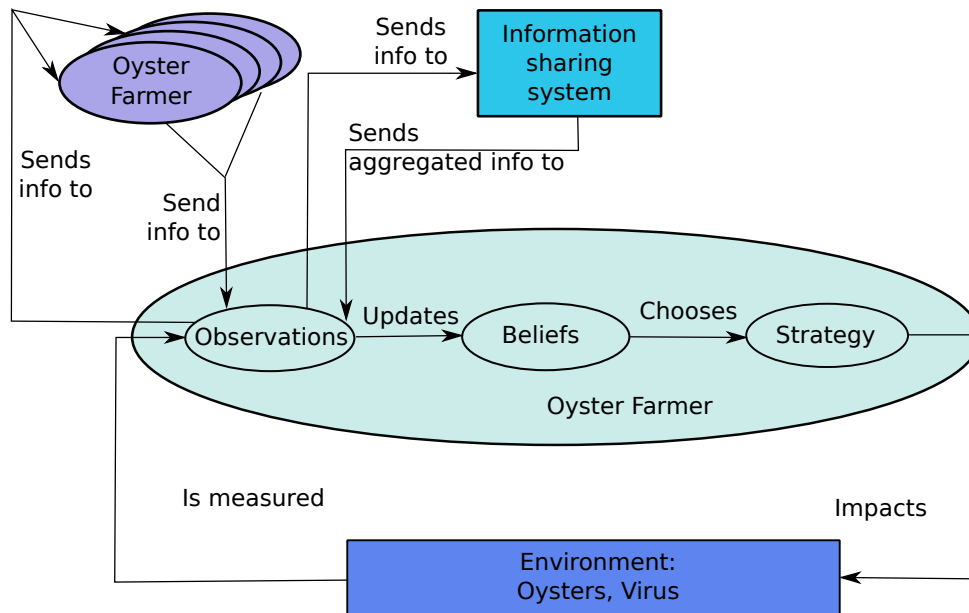


Figure 11.4: Main loop of the model.

system. Information provided to friends and to the information system are the same, but the values that flows back to the agents are different since they are based on different sets of information. This information is compiled through an aggregation method (see “Learning”, p.178) that enables the agent to update her beliefs and then choose a strategy. These strategies are implemented and impact the environment (the oysters and the virus).

The main step is shown in the sequence diagram (Figure 11.5). Each step lasts for a trimester: several steps only occur during specific trimesters in the year. The virus attacks only during the second trimester and oyster farmers choose their mix at the end of that trimester. Natural catchment can only occur during summer, the third trimester of each year.

11.1.2 Design concepts

The following paragraphs contain all concepts listed in the ODD+D protocol in an order that makes the description as easy to read as possible (Müller et al., 2013). As explained above, there are three main classes in the model. Among them, `Oyster` and `WaterCell` have very simple behaviors. Thus, I focus on `OysterFarmer`.

Theoretical and empirical background I used a mixture of empirical and theoretical elements to construct the model. As explained in Chapter 5, empirical data comes from the case study investigation with semi-structured

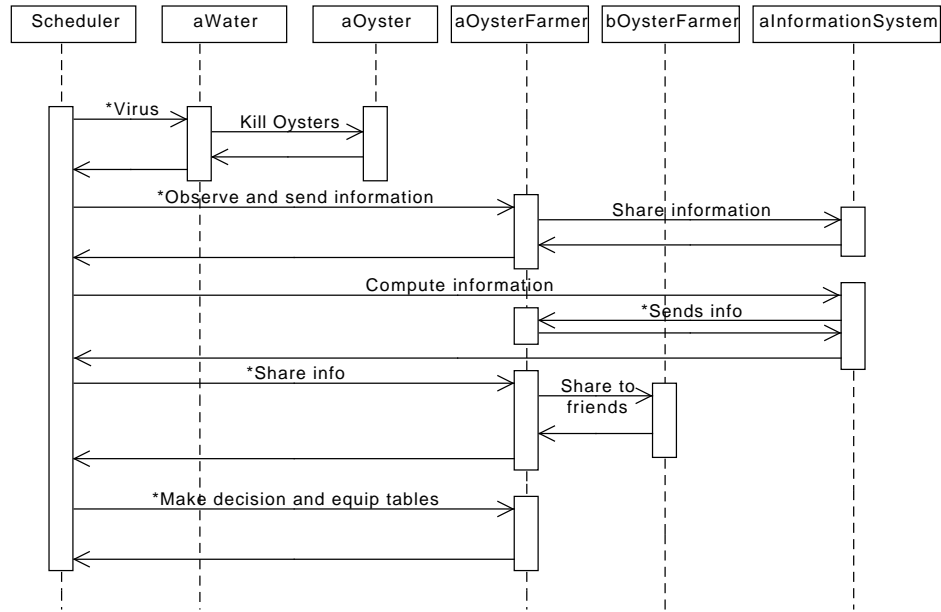


Figure 11.5: Sequence diagram for the main step of the model. Such a step lasts for one trimester.

interviews, participatory observation, and used gray and official literature and reports.

Theoretical choices have been guided by [An \(2012\)](#) who suggests some categories that may be used by modelers of human decision-making in coupled humans and natural systems (CHANS). I use several of these categories. First, I ruled out participatory methods (the model is first intended as theoretical), space-based decision making (oyster farms are fixed) and evolutionary programming (behaviors, but not beliefs and decisions, are fixed during the initialization). I focused on psychosocial and cognitive models: agents have beliefs about the environment and the consequence of their actions on their income and production (see “Individual prediction”, p.178) which can be partly shaped by an institution, the information sharing system. I implemented different decision models for each type of **OysterFarmer**. Specifically, “economicus” use a microeconomic model of utility maximization and “conservative” use a heuristic rule following a procedural rationality ([Simon, 1976](#)).

[Narukawa \(2007\)](#) describes thoroughly a large number of decision models based on information coming from different sources that have to be aggregated. Information fusion can be done basically following two modeling frameworks: probability and fuzzy reasoning. I chose a probabilistic approach since observations (as described further) are realizations of events based on independent and identically distributed random variables. Since agents are using these

Table 11.1: Networks scenarios used in the model

Type of network	Description	Expected effect
Neighborhood graph	Each agent is friend with immediate neighbors (2 on each side)	Slow diffusion of information, local learning
Preferential attachment	Variation of the small world network where new nodes are attached preferentially to those who are most connected.	Fast diffusion of information, some nodes who have more influence than others
Homophily network	Agents are preferentially linked to agents who have chosen the same mix	Clustering and slow diffusion of information

realizations to build personal beliefs and need to cope with uncertainty, a probabilistic approach based on a weighted average operator is natural (see “Learning”, p.178).

Individual sensing Agents sense production and mortality rates of oysters located on their farms. They gather exact information. Agents get information about other oyster farmers’ results through the means of social networks and an information sharing system (see “Interaction”, p.177).

Interaction The virus acts independently on each oyster farm, there is no specific interaction at the resource level. Rather, interactions occur at the information sharing level: networks and central information sharing system. Network types influence learning and innovation diffusion (Jackson et al., 2008). Thus, I designed three graph scenarios (Table 11.1). Agents send information to and receive it from friends through their network. The first scenario, neighborhood graph, is based on interviews of oyster farmers in the Thau Lagoon saying that they often had little or no relation with others, and mostly with neighbors. This observation is possibly specific to the Thau Lagoon and may even not be precise enough to describe the local network since I did not conduct a social network analysis.

The second is a classical network found in many real life examples: the preferential attachment network (Barabási and Réka, 2002). Its main characteristics are its small diameter and the presence of hubs (nodes with high degree), allowing fast spreading of information through the network. The first two networks are created during the initialization.

The last type of network is based on homophilia (Golub and Jackson, 2010; Jackson and López-Pintado, 2013), where oyster farmers that choose the same

strategies are more likely to exchange information. The network is entirely recreated every 12 steps (3 years). Since agents collect mostly information from people who are alike, the main expected effect of this kind of network is to make innovation processes slower.

Collectives Agent do not interact directly in a collective. However, there is a collective object: the information sharing system. I use the typology given in Chapter 4 to describe thoroughly the information sharing system. The goal of the system is to collect information about mortalities experienced by oyster farmers practicing different methods. All oyster farmers can write personal and local information, all oyster farmers can read aggregated information. It is possible to consider that a dynamic fraction of the population contributes or reads, but the study of extreme situations needs to be conducted first to determine whether the model should be pushed further. Granularity of information received by agents is limited to a single value (actually, a set of values for each type of oyster): the system averages agents observations for all types of oysters and classes of oyster batches. The information system is updated annually since the virus hits once a year.

The information system is well designed since the information it gathers and computes is a theoretically convergent model of the virus dynamics. The more information the system gets, the more precise the information aggregated in the model is. There are two possible discrepancies between virus dynamics and the representation in the model: no agent chooses a specific practice, leading to absence of information; too few agents provide information, leading to biased results.

Learning Learning comes through observation of the environment, information exchange with friends and information aggregated in the information sharing system.

For each type of oyster, oyster farmers obtain three distributions of observations: their personal observations, their friends' observations and the aggregated information provided by the system. Then, agents perform a combination (a weighted aggregation) of those distributions to obtain their own beliefs on mortality rates. See Table 11.2, Figure 11.6 and the paragraph on "Individual decision making", p.180, for a description of mortality belief construction.

Personal learning is the main goal of information exchange in the present case of private threat. Collective learning appears in the external representation created by the information sharing system that agents use for their own decision making.

Individual prediction The distributions obtained during the learning phase allow agents to make their prediction of future mortalities and update their

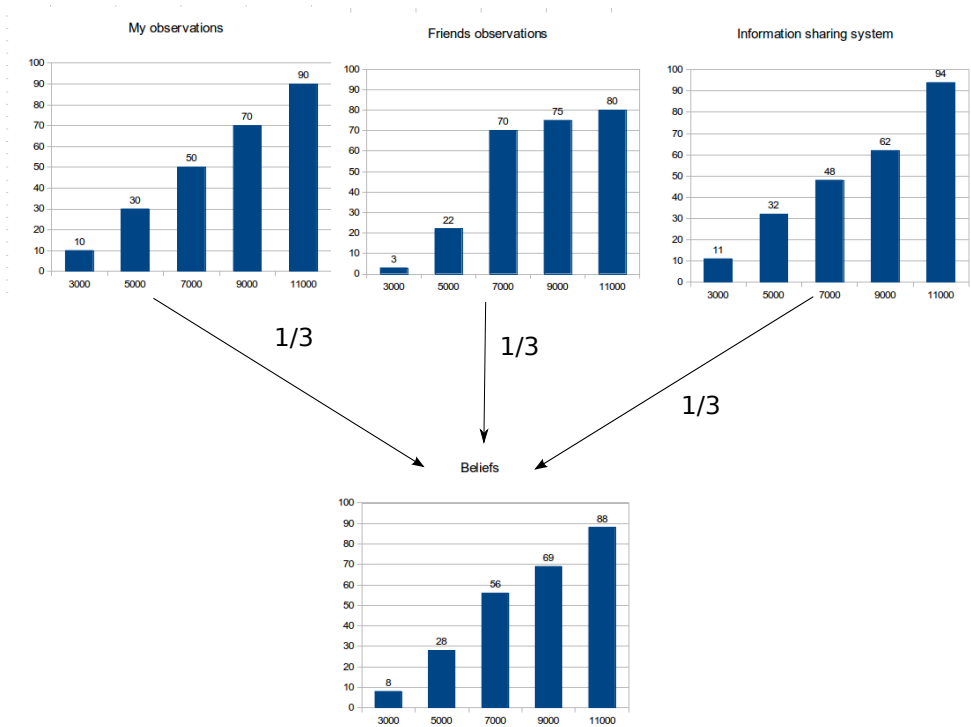


Figure 11.6: Averaging of individual, friends and information system observations with coefficients $(a, b, c) = (\frac{1}{3}, \frac{1}{3}, \frac{1}{3})$. This operation is done for each of the three types of oysters.

Table 11.2: Aggregation scenarios - coefficient used for distribution aggregation. Scenarios are compared to the no information sharing one. ISS = information sharing system

Own	Friends	ISS	Type	Expected outcome
1	0	0	No information sharing	Slow learning curve
$\frac{1}{2}$	$\frac{1}{2}$	0	Own and friends experience	Increased learning
$\frac{1}{2}$	0	$\frac{1}{2}$	Own and ISS	Increased learning
$\frac{1}{3}$	$\frac{1}{3}$	$\frac{1}{3}$	Equal trust among sources	
0	0	1	Use only the ISS	Important variations - Converge to the same strategies with little exploration

ideal quantities of oysters per batch, the first step of their decision-making process. Their predictions are actually beliefs that can be erroneous since based on their own experience, their friends' and the information gathered in the information sharing system.

Individual decision-making Figure 11.7 shows the activity diagram for agents decision-making. An agent has to choose sequentially every year their ideal quantities per batch $Q = \langle Q_t, Q_d, Q_n \rangle$ for each type of oysters and a mix $M \in \mathcal{M}$ of oysters among triploids, diploids and naturals, where \mathcal{M} is the set of possible mixes in proportions. \mathcal{M} consists of only one type, two or three types of oysters equally divided, *i.e.* 7 choices¹.

Oyster farmers are endowed with tolerance levels, the same for all farmers, T_{min} and T_{max} , with $T_{min} < T_{max}$ that they use to increase or decrease the number of oysters they think is good per batch. The increase and decrease are of a parameter $q > 0$. These parameters can be modified to make farmers more or less risk adverse or taker. Thus, they use the following formula to choose their ideal quantity Q_i , $i \in \{t, d, n\}$, at time $t + 1$, for all three kinds of oysters:

$$Q_i(t+1) = \begin{cases} Q_i(t) - q & \text{if } mort(Q_i(t)) > T_{max} \\ Q_i(t) + q & \text{if } mort(Q_i(t)) < T_{min} \\ Q_i(t) & \text{otherwise} \end{cases} \quad (11.1)$$

Q is updated in the same way for all agents. It is the answer to the following question: "If I had to use these oysters, how many should I use per batch?" After choosing these ideal quantities, agents can choose a mix using an expected profit computation.

Several models for decision making are designed according to the category the agent belongs to, specifically:

1. If the agent is **economicus**, she uses a microeconomic model where she maximizes her utility (the expected profit) over the set of mixes \mathcal{M} she can choose from using the following formula:

$$M = \operatorname{argmax}_{M_i \in \mathcal{M}} \sum_{i \in \{n, d, t\}} M_i \cdot Q_i \cdot (s \times (1 - mort(Q_i))^{expo(i)} - b_i) \quad (11.2)$$

where s and b_i are respectively the selling (which is independent from oyster type) and buying prices, $expo(i)$ is the exposure of each kind

1

$$\mathcal{M} = \left\{ (1, 0, 0), (0, 1, 0), (0, 0, 1), \left(\frac{1}{2}, \frac{1}{2}, 0\right), \left(\frac{1}{2}, 0, \frac{1}{2}\right), \left(0, \frac{1}{2}, \frac{1}{2}\right), \left(\frac{1}{3}, \frac{1}{3}, \frac{1}{3}\right) \right\}$$

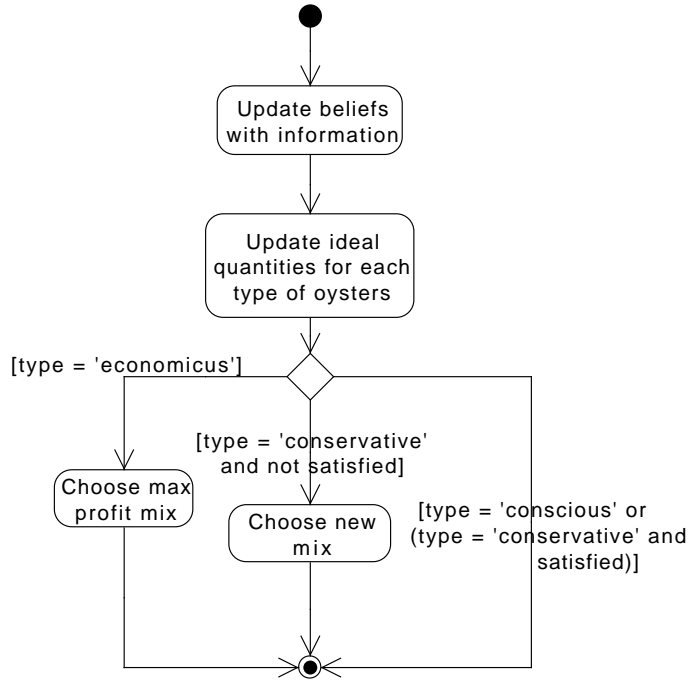


Figure 11.7: Activity diagram: belief update and decision making process

of oysters. Since triploids live only 18 months, they are on average exposed 1.5 times during their lifetime, while other kinds are exposed 3 times. $(1 - \text{mort}(Q_i))^{\text{expo}(i)}$ corresponds to the believed survival rate. For simplicity, I made the hypothesis that mortality is independent from oyster age.

2. If the agent is **conservative**, then she will keep M^i as long as it is satisfactory. The agent is satisfied if M^i provides a positive income. If she is no longer satisfied, then she chooses randomly a mix $M \in \mathcal{M}$ and computes the profit using Equation 11.2 until she finds one she predicts would give her a positive income.
3. If the agent is **conscious** then she never changes M^i , growing only natural oysters. This type of agent is important in the population for information sharing purposes.

Heterogeneity Agents are heterogeneous mainly in two ways:

1. Type: This has an influence on the decision making process, more precisely the mix choice.

2. Information use: Agents have different ways of weighting information from the three sources.

Stochasticity The virus randomly affects according to fixed probabilities following the scenarios described in “Entities, state variables and scales” (Figure 11.2). During the initialization, oyster farmers are endowed with a random number of tables. The preferential attachment network has some stochastic elements (the order of agents enter the network and the agent they are first connected with) and the homophilia network is shuffled every 12 steps following a stochastic rule. When they need to change their mixes, “conservatives” randomly try different mixes until finding an acceptable one.

To gum out stochasticity, I have chosen to repeat 40 times each scenario. This number is high enough to make convergence effective.

Observation Data are collected at each time step. The following indicators are saved: mortality rates and total production for the environment; batch size, mix types and agents’ beliefs.

11.1.3 Details

Implementation details The model is implemented in Cormas v.2014.5.14. (Bousquet et al., 1998; Le Page et al., 2012), a multi-agent developing platform specifically designed for situations where humans interact with a natural environment. It proposes an agent-based meta-model organized around three main classes of entities: agents, spatial entities and objects (passive entities). It is coded in the smallTalk language and uses a VisualWorks software. Scenarios were generated and outcomes analyzed with R v.3.2.1 (R Core Team, 2015) through RStudio v.0.98.1102 (RStudio Team, 2012). This model led to developing a module that links R and Cormas. Model, data, scripts and documentation are available on open ABM (at the moment of printing this thesis, the model is submitted and should be available).

Initialization At the initialization, oyster farmers are equipped with tables, and a random mix (only natural if the farmer is ‘conscious’), tables are loaded with batches of oysters in the proportions given by the mix. Farmers are not aware of the existence of the virus and have beliefs of zero mortality for all oysters. See next section to get initial parameters.

11.1.4 Submodels and parameters

Oyster farmers type distribution I defined three scenarios for population distribution. A type is described with a triplet of proportions of each type of farmers $< P_{economicus}, P_{conservative}, P_{conscious} >$. I supposed that there are always “economicus” agents. I studied situations where there are only

Table 11.3: Experimental plan.

Factor	Parameter(s)	Modalities	Scenarios
Farmer type	$\langle P_{eco}, P_{consc}, P_{consc} \rangle$	$\langle 1, 0, 0 \rangle$, $\langle \frac{1}{2}, \frac{1}{2}, 0 \rangle$, $\langle \frac{5}{12}, \frac{5}{12}, \frac{1}{6} \rangle$	3
Number oyster farmers	Number	10, 25, 50, 100	4
Decision making	{Quantity, $\langle T_{min}, T_{max} \rangle$ }	{500, $\langle 40, 70 \rangle$ }, {500, $\langle 60, 80 \rangle$ }, {2000, $\langle 40, 70 \rangle$ }, {2000, $\langle 60, 80 \rangle$ }	4
Virus	Mortality rates	Figures 11.2 and 11.3	3
Information sharing and social networks	\langle Personal, Network, ISS with Personal, ISS \in {Yes, No}, Network \in {None, Neigh, Pref, Homo}	\langle Yes, Any, No \rangle , \langle Yes, Any, Yes \rangle , \langle No, None, Yes \rangle	9

“economicus” $\langle 1, 0, 0 \rangle$, “economicus” and “conscious” $\langle \frac{1}{2}, \frac{1}{2}, 0 \rangle$ and the three types $\langle \frac{5}{12}, \frac{5}{12}, \frac{1}{6} \rangle$ (“conscious” are a rare type).

Number of oyster farmers I chose four scenarios: 10, 25, 50, 100. All oyster farmers are given an initial budget allowing them to fill twice all their tables with triploids.

Social network scenarios I chose three scenarios: neighborhood, preferential attachment and homophilia networks (see “Interactions” and Table 11.1).

Information sharing I defined five information sharing scenarios, where agents mix their own experience, their friends’ and information gathered in a collective system (Table 11.2). Also see “Learning”.

Decision making This factor is driven by two dimensions: the importance of change in quantities, q , and risk aversion, T_{min} and T_{max} (see “Individual decision-making” and Equation 11.1). I have kept two values for q : 500 (small change) and 2,000 (big change); and two sets of values for the $\langle T_{min}, T_{max} \rangle$ ordered pair: $\langle 40, 70 \rangle$ (risk adverse) and $\langle 60, 80 \rangle$ (risk taker). There are four decision making scenarios.

Virus Three scenarios are tested: no virus and virus with or without overlapping lethal rates (Figures 11.2 and 11.3).

In total, there are $4 \times 2 + 1 = 9$ combined scenarios for graphs and information sharing. There are $3 \times 4 \times 4 \times 3 = 144$ for the rest of the parameters. In total, I tested $9 \times 144 = 1296$ scenarios. All those scenarios were run and repeated 40 times. These scenarios are summed up in Table 11.3.

11.2 Analysis

To analyze simulation outputs, I follow the main steps of the model as described in Figure 11.4. Such a method enables a thorough tracking of consequences of information sharing at different stages. First, I examine the environment (*i.e.* oysters) displaying variations of graphs on three indicators: mortality rates, total production and size of batches. After showing simple graphs, I plotted differences between information sharing scenarios and the no information sharing one, and between network scenarios with and without information sharing system. Then, I focused on agents tracking evolution of oyster farmers' beliefs (distance with theoretical virus dynamics and pure beliefs) and practices (types and change of mixes).

I looked at an aggregated level. Most graphs of the following tables result from the aggregation of 48 different scenarios (4 population, 3 types of oyster farmers and 4 decision scenarios) each repeated 40 times. The idea behind these graphs is to try to find general behaviors allowing to draw broad conclusions or to suggest ways to explore further.

For most of the following graph tables, I represented Virus \times Information scenarios: virus situation in rows and information sharing scenarios in columns. Neighbor, Preferential and Homophilia are situations where agents share information through different types of networks (Table 11.1). The apposition of ISS (as for Information Sharing System) adds to the previous type of network.

11.2.1 Oysters and environment

Global view The first indicators are linked to the environment, and thus oysters, through density and health. I inspect three indicators: mortality rates (Figure 11.8), total quantity of oysters (Figure 11.9) and average size of batches (Figure 11.10).

Figure 11.8 shows that in the “overlapping” scenario, triploids mortality rate plateaus at 60% for all information sharing scenarios, except the “homophilia” that reaches 65% and the “ISS only” that displays lower rates, 55%. In the “no overlapping” one, triploids initial mortality rate of 80% drops to 60% in 20 steps for the personal, neighbor and preferential attachment situations, with or without ISS (and even down to 45% in the “ISS only” scenario), while the homophilia scenario leads to higher mortality rates (65%). The other two types of oysters follow the same path with an initial increase over 20 steps and further decrease with the same type of differences between information sharing scenarios (these differences are more specifically tackled in the following paragraph).

As far as production is concerned, a combination of Figure 11.9 and 11.10 allows to understand how oysters are grown in the estuary. Cyclic variations are an artifact of initialization. In the “overlapping” scenario, production of

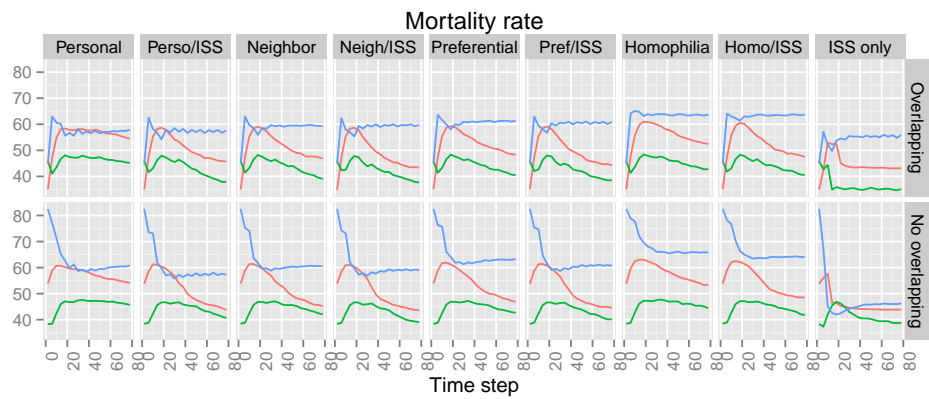


Figure 11.8: Mortality rates.

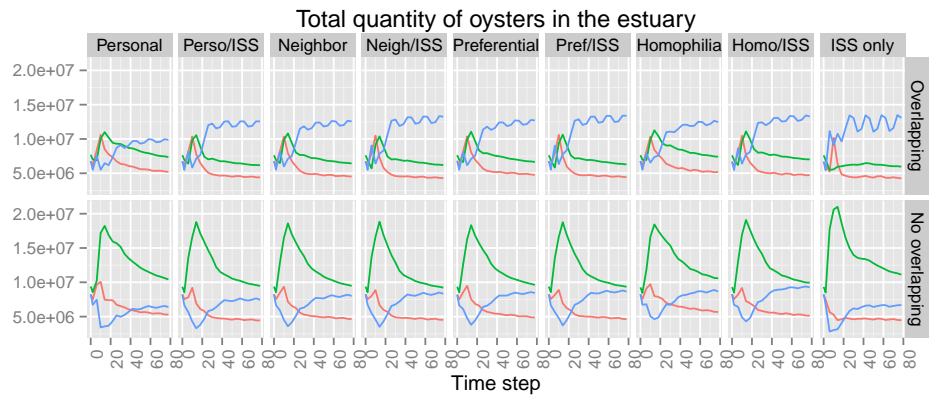


Figure 11.9: Quantity of oysters.

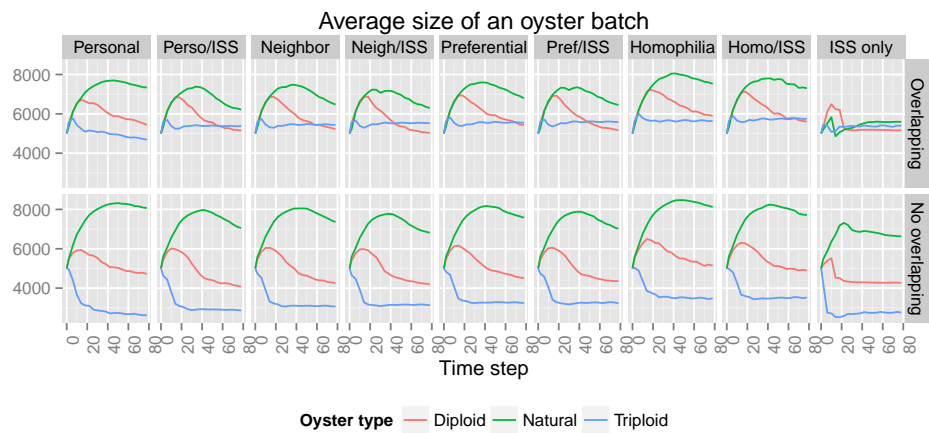


Figure 11.10: Average size of an oyster batch. Maximum size is of 10,000 oysters.

triploids is low during 10 steps and steadily increases in all scenarios, with a bigger production in scenarios where information is shared (compared to the “personal” scenario). Naturals and diploids follow the same pattern with an initial increase of production that gradually declines at the expense of triploids. The size of triploid batches hardly change, while the size of batches of naturals and diploids increases first to decrease after respectively 40 and 20 steps. In the “no overlapping” scenario, initial production and size of batches of naturals is doubled within 5 steps to decline progressively at the expense of a slight growth in triploid production, stored in batches of small size (3500 oysters while batches may contain up to 10,000). The “ISS only” scenario shows a particular behavior with lower sizes of batches for an increased production of naturals and lower production of triploids in “no overlapping”.

Adding information In this paragraph, I adapted the graphs described above to compare information sharing scenarios with the “personal” one. Lines are above (resp. below) zero if the value has increased (resp. decreased) compared to “personal” (I calculated “value of new scenario minus value of ‘personal’ scenario”). Figure 11.11 shows differences in relative mortality rates. In the “overlapping” scenario, the addition of any type of information sharing, except “ISS only”, leads to a decrease of mortality rates for diploids and naturals of 10%, and an increase of less than 5% for triploids. In the “ISS only” scenario, drops in mortality rates are valid for all types of oysters. These changes begin to be noticeable after 5 years (20 trimesters). In the “no overlapping” scenario, changes are minor regarding triploids for all scenarios except in the “homophilia” network case where results are worse, and in the “ISS only” one where triploids mortality ebbs by more than 20% to finally reach minus 15%. Mortality rates for naturals show little variations along time, while diploids converge towards a minus 10% in all cases but the “homophilia” that leads to results close to non information sharing scenarios.

Figure 11.12 represents differences in total quantity of oysters grown. It appears that in the “no virus” case, oyster farmers tend to choose and grow triploids (not represented in the figure). It is coherent with what occurs in real-life since it is by far the best economic option. Agents initially favor natural oysters with a decrease of this quantity and an increase in triploid growing along time in the “no overlapping” scenarios. The “overlapping” scenarios show a higher rate of triploids being grown. The impact of information sharing scenarios here are difficult to perceive, but the “ISS only” scenario leads to amplified effects compared to the other situations.

Finally, in Figure 11.13, I plotted the differences in average batch size. In the “overlapping” scenario, batch sizes for triploids increase in a similar fashion, reaching a size of 1,000 more oysters after 20 years than in the no information sharing case. Diploids follow a close trend, and naturals are diminished, except in the “homophilia” scenarios where values keep following changes observed in

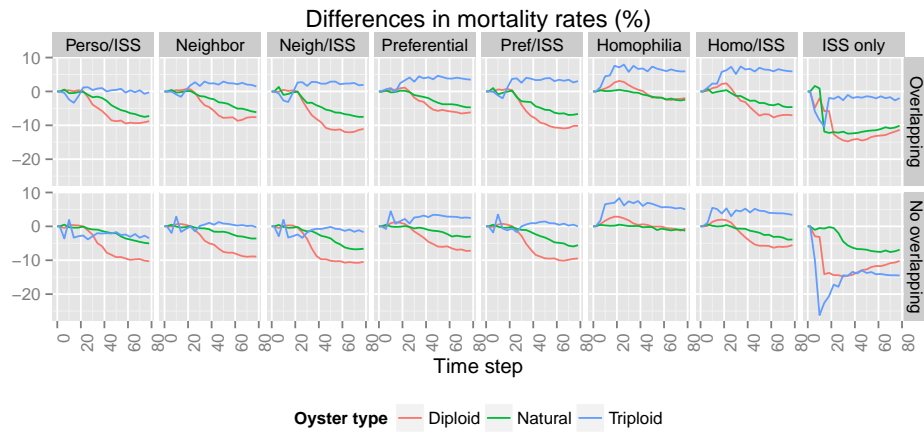


Figure 11.11: “Personal” scenario is taken as a base for comparison. These graphs represent the difference between the named scenario and “personal”. A line below zero means that sharing information leads to lower mortality rates. The apposition of “ISS” adds the information sharing system to the previous network type.

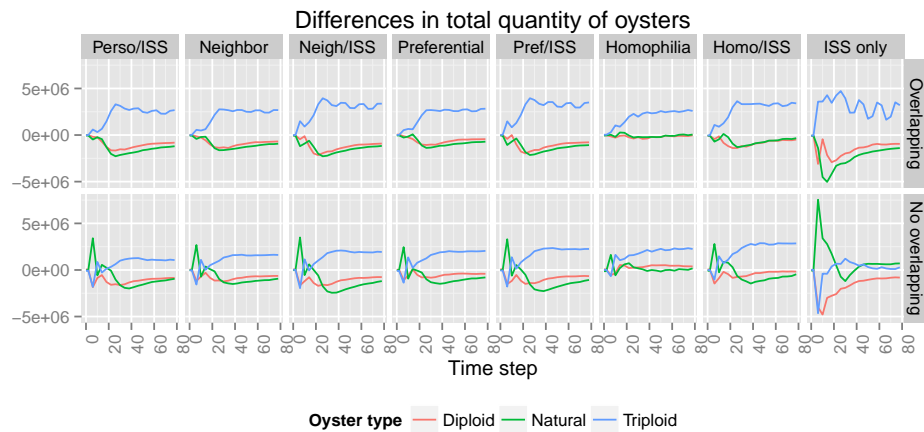


Figure 11.12: Differences in quantity of oysters compared to “personal”.

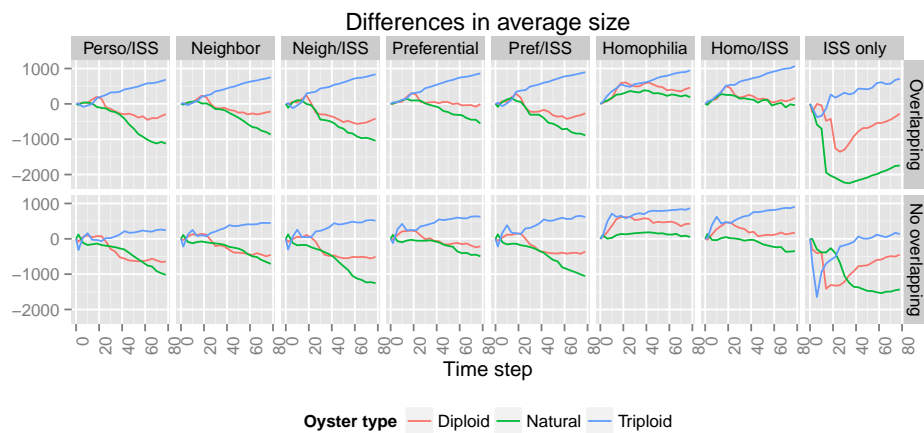


Figure 11.13: Differences in average size of oyster batches. Maximum size is of 10,000 oysters.

the “personal” scenario. The “ISS only” case has once again a specific behavior with batches of diploids and naturals quickly dropping by respectively 1,000 and 2,000 oysters. This number is increasing again after this drop. In the “no overlapping” scenario, trends are similar, except in the “ISS only” case where triploid batches are also diminished by 2,000 oysters in the beginning, catching up with no information levels after 40 steps (10 years).

Globally, these graphs show that the use of information by actors leads to significant changes in mortality rates, in batch sizes and quantity of oysters grown. Implementing an ISS systematically diminishes mortality rates. The “ISS only” case shows a specific behavior that calls for more investigation.

ISS vs no ISS One of the main goals of the model is to understand consequences of implementing an information artifact. In this paragraph, I follow this idea to plot the same indicators as in the previous ones focusing on comparing information scenarios with and without artifact for each type of initial network. Results are shown in Figures 11.14, 11.15 and 11.16.

Whatever the network, mortality rates (Figures 11.14) are always lower with the addition of the ISS, except for triploids that do not show any improvement, while triploids represent the most important production. The most drastic effect is obtained when the ISS is added to the “personal” scenario (mortality rates diminish by 10% for diploids and naturals in the “overlapping” case).

Total quantity of oysters in the estuary (Figure 11.15) are similar with and without ISS, once again except in the “personal” scenario where changes are tangible. The last graph showing average size of batches (Figure 11.16) gives similar results: changes linked to the addition of an ISS are limited except in the “personal” case that displays wider variations than with the other types of scenarios.

Globally, the addition of new information is mostly useful when agents have no direct record of experiences of other oyster farmers, that is, in the “personal” scenario. This effect is due to the availability of a much wider set of experiences through the ISS than with their own. In cases where oyster farmers have access to a network of other farmers, differences created by the ISS are close to null.

Global production So as to understand effects of information sharing in the long run, I represented the cumulated total of production and mortality over time in Figure 11.17 and 11.18 using the same comparisons as in the previous paragraphs (comparison to “personal” and situations with - without ISS). In these graphs, I plotted results as variations in percentage for oysters regardless of type.

When comparing to the “personal” scenario (Figure 11.17), we can see that in the “overlapping” virus case mortality and production increase, espe-

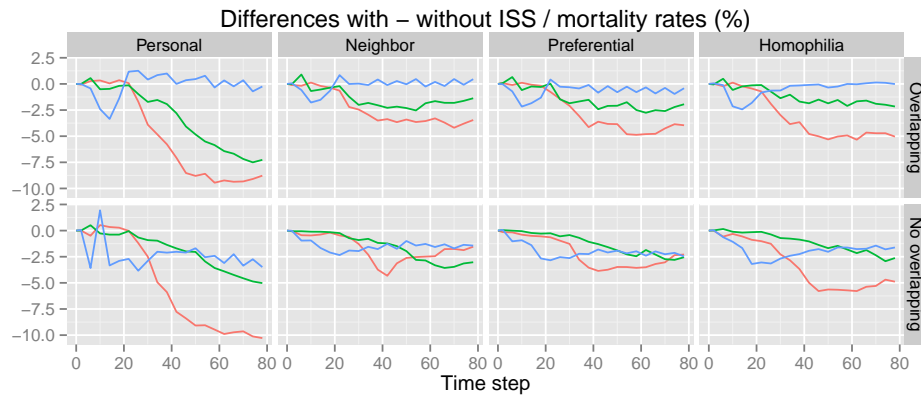


Figure 11.14: Differences in relative mortality rates.

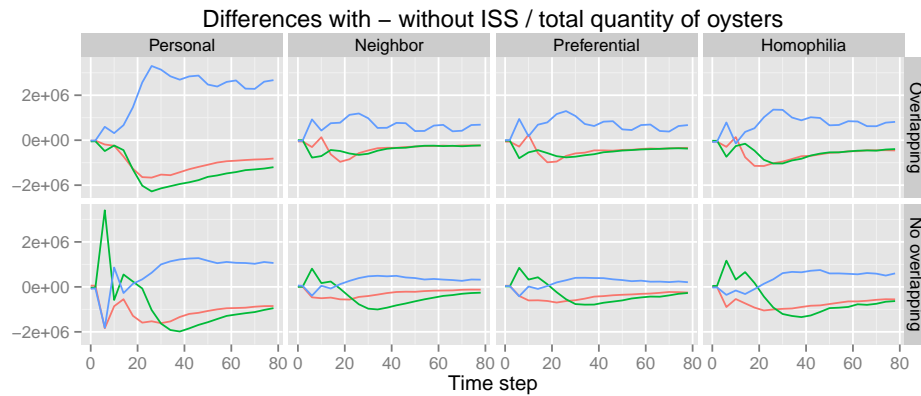


Figure 11.15: Differences in total quantity of oysters.

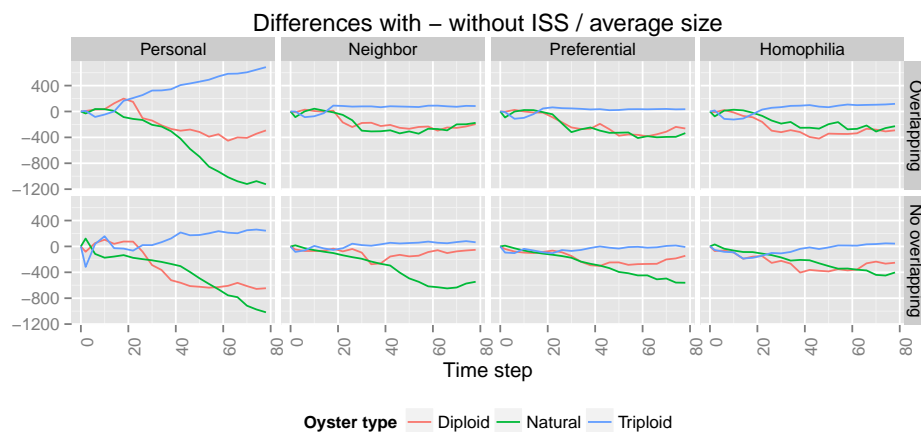


Figure 11.16: Differences in batch size. Maximum size is of 10,000 oysters.

Figures show, for each type of information sharing network scenario differences between situations with and without ISS. A line above zero (resp. below) means that production or mortality increased (resp. decreased) by $x\%$ with the addition of new types of information sharing media.

cially in the homophilia case (more than 10% increase in mortality and almost 10% increase in production), while the “ISS only” situation is the only one in which production and mortality initially decrease to catch the levels of the “personal” scenario after 20 years. In the “no overlapping” case, except for the “homophilia” scenario, overall mortality and production are decreased by 5%, and by 15% at the beginning for the “ISS only” scenario that catches back the “personal” scenario at the end of the simulations. As in the previous virus scenario, “homophilia” scenarios lead to steady increases in both mortality and production over the years. This graph shows less visible effects than those that can be observed in Figure 11.11 since triploid mortality hardly changes in the various information sharing scenarios while it is by far the most popular choice of oyster in all scenarios.

The general tendency when comparing situations with and without ISS is that the effect of the ISS is limited (Figure 11.18). It is most visible in the “no overlapping” case when an ISS is added to the “personal” situation. The effects in other situations are negligible (less than 5% variations over 20 years).

11.2.2 Oyster Farmers

What are the global effects on agents?

I observed two different sides of oyster farmers. Following the step listed in Figure 11.4, first, I investigated how agents’ beliefs evolved with information. Second, I looked at how their practices (their choice of oysters to grow) changed with time, tracking along choices made by agents. It is useless to study income which is a multiple of production (the market buys all oysters at the same price).

Beliefs I measured how oyster farmers’ beliefs changed in two ways: the range of beliefs and the distance between beliefs and the real virus dynamics. The first indicator measures dispersion of beliefs among the group of agents, *i.e.* convergence in mental representations, while the second measures whether these beliefs are close to a real knowledge of the virus.

Figure 11.19 shows boxplots, mapping distribution on mortality beliefs at three different steps: after 2, 5 and 20 years. I chose to display the “overlapping” scenario, the equivalent graph for the “no overlapping” being similar. Along the years, except for the “personal” scenario, dispersion of beliefs is decreasing and seems to be converging towards values roughly shared by agents. The addition of the ISS leads to an even more condensed range of beliefs.

However, this convergence in beliefs is not necessarily correlated with a more accurate knowledge of the environment dynamics. Figure 11.20 represents the euclidean distance between what oyster farmers believe and the real virus dynamics at the end of the simulation.

In the model, the situation where agents have beliefs closest to the real virus dynamics is the “economicus” only one where bars are shorter than in

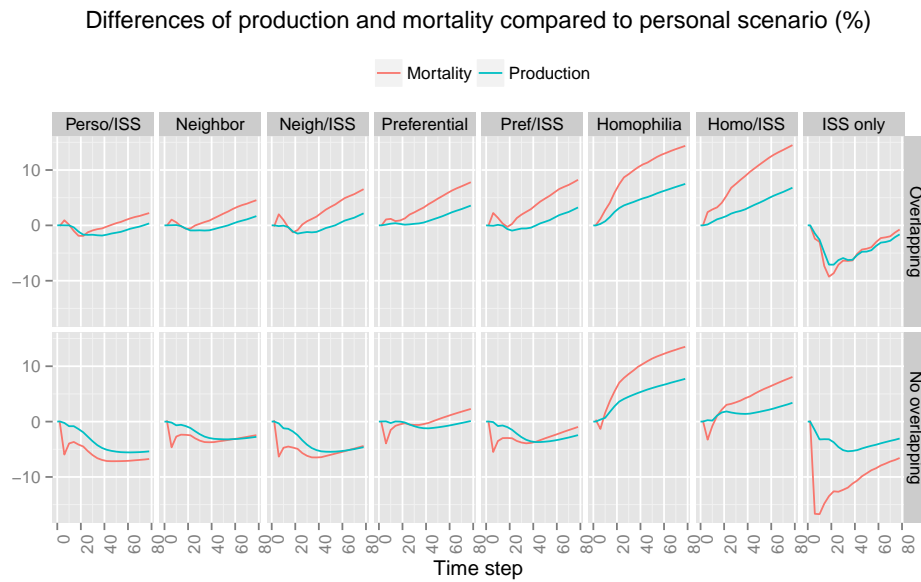


Figure 11.17: Cumulated differences in mortality rates and production over the year compared to the “personal” scenario. A line above zero (resp. below) means that production or mortality increased (resp. decreased) by $x\%$ with the addition of new types of information sharing media.

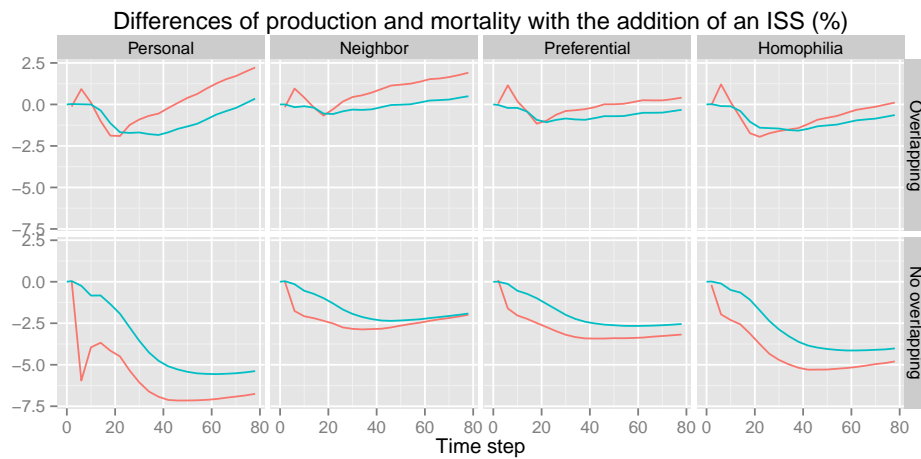


Figure 11.18: Same as above with a comparison of the effect of adding an ISS to a network.

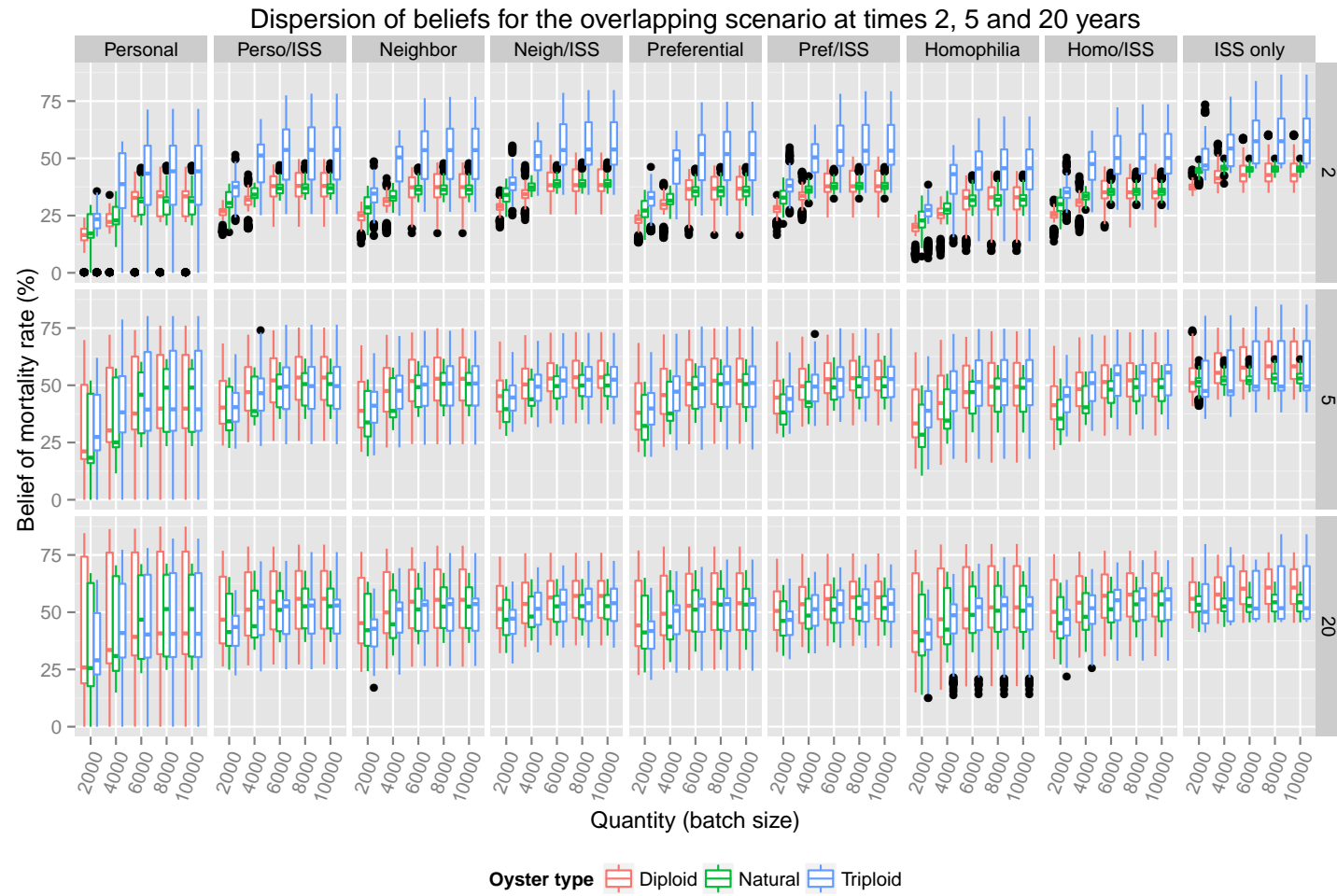


Figure 11.19: Dispersion of oyster farmers' beliefs on mortality rates for different batch sizes. In rows, I represented different time steps corresponding to 2, 5 and 20 years after initialization.

the other two situations. Small variations of quantities and low risk taking leads to beliefs closer to the truth than others. The addition of any type of information system (a global one and/or a network) creates more precise results (beliefs are closer to the truth by 20%), especially in the “economicus, conservative and conscious” scenario, except in “big change - high risk” where the “ISS only” beliefs are less precise than with other types of information sharing. Except from those observations, for a given population mix, results do not vary according to information sharing scenarios.

Practices As for oyster farmers changing their mixes (Figure 11.21), the aggregated effect is once again difficult to grasp. Differences between population types scenarios are clearly visible: when the population is entirely constituted of “economicus” agents, changes occur much more frequently than with other types of agents. It is possible to see that the addition of various networks types and the information sharing system moves the curves to the left, fastening the decrease in changes. The pure ISS case exhibits the quickest drop in mix changes. Differences between information sharing scenarios are not blatantly apparent but these represent an aggregation of diverse scenarios which gums out trajectories. This limit does not prevent these graphs from being instructive. The most noticeable, and seemingly shared by all scenarios, element is that the share of oyster farmers changing their mixes converge towards zero. This observation gives the idea of building convergence indicators that would measure the time step at which this convergence occurs.

Evolution in practices can be globally observed in Figure 11.22 where I represented choices of oyster mixes by farmers. In all cases, triploids are preferred compared to other types of oysters. In the “no virus” scenario, those who do not choose to grow triploids are “conscious” oyster farmers who only grow naturals and “conservative” who never have a reason to change their initial mix, randomly allocated during the initialization. In the “no overlapping” scenario, natural oysters seem to be chosen at the beginning: they are the best economic option. Little by little they are replaced with triploids while they are less profitable. The “overlapping” scenario shows a faster growing rate for triploids than for the others, possibly due to difficulties in interpretation of mortality information. For a given virus scenario, it is possible to observe differences between information sharing scenarios, but only in terms of convergence speed.

In Figure 11.21, it appears that changes are convergent, but it is difficult to observe differences clearly, even with a graph of differences. This fact prompted me to define an indicator of convergence for mix changes that I defined as the time step after which less than $x\%$ of agents change its mix. I called such an indicator *change convergence*. This is a limit in the influence of information. Since only a single value is defined per scenario, such an indicator allows for a disaggregation of scenarios compared to the previous representations which

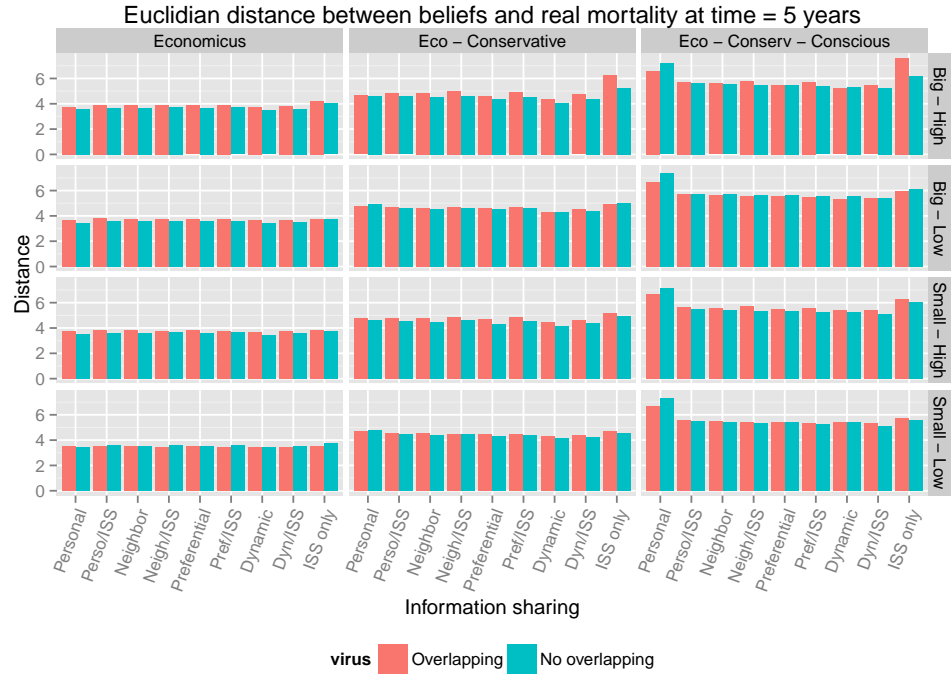


Figure 11.20: Averaged euclidean distance between oyster farmers’ beliefs and real virus dynamics after 5 years. The closest the bar is to 0, the closest oyster farmers’ beliefs are to reality. In columns are the 3 population scenarios, in rows, the 4 decision-making scenarios and each couple of columns represent one of the 9 information sharing situations. “Economicus” only show the closest belief to reality. The effect may be linked to a wider exploration than other types of farmers due to their search for maximal income.

combined them. In Figure 11.23, I have plotted the convergence indicator for 5% of farmers and plotted the three quartiles of the 40 simulations as concentric disks.

The addition of an ISS systematically leads to faster convergence, with a dramatic effect of almost immediate convergence in the “ISS only” scenario, except when there are only “economicus” agents. In “personal” and “homophilia” scenarios, there is no convergence whatever the other parameters of scenarios. Within a single facet, for instance “Neigh/ISS” \times “NO-ECs”, convergences may vary from simple to double due to parameters such as decision or population size which makes global conclusions on the role of information sharing hard to draw.

Information hastens convergence, but does faster convergence lead to better results for the environment and agents? Total production during the simulation is an indicator that can be used as one linking the environment and agents

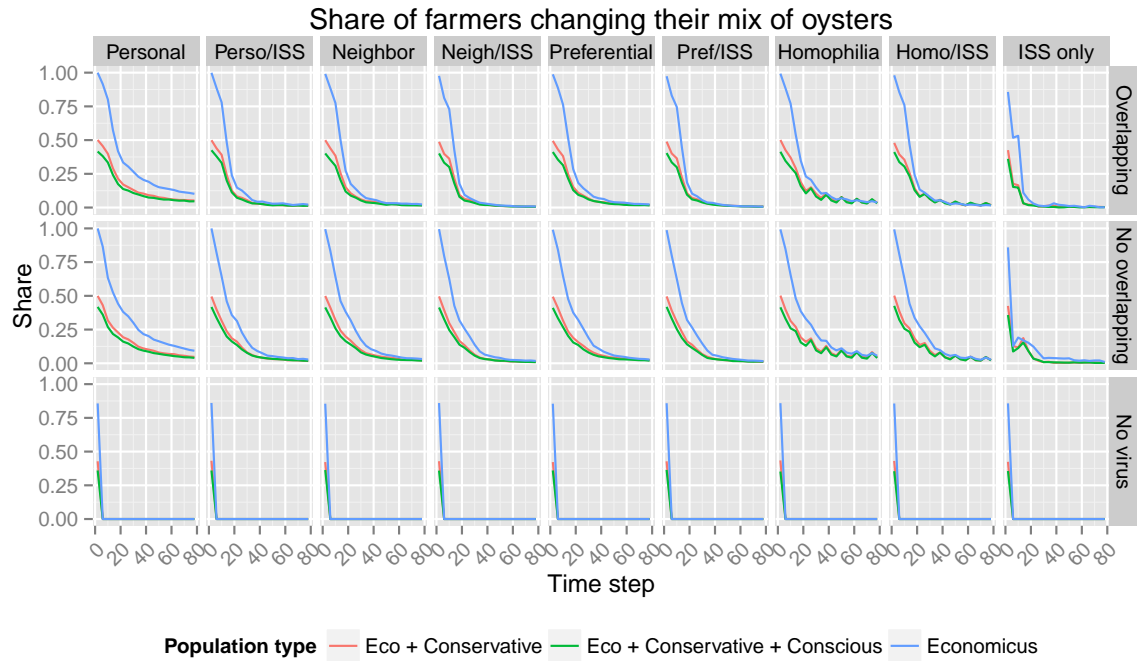


Figure 11.21: Share of oyster farmers changing their mixes along time.

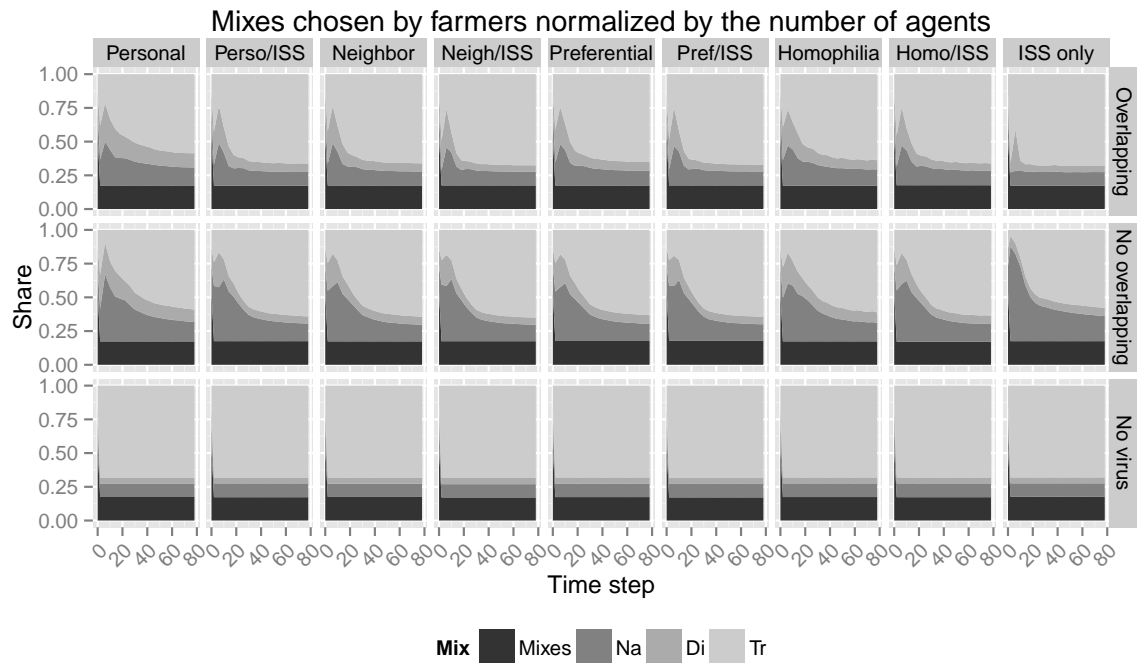
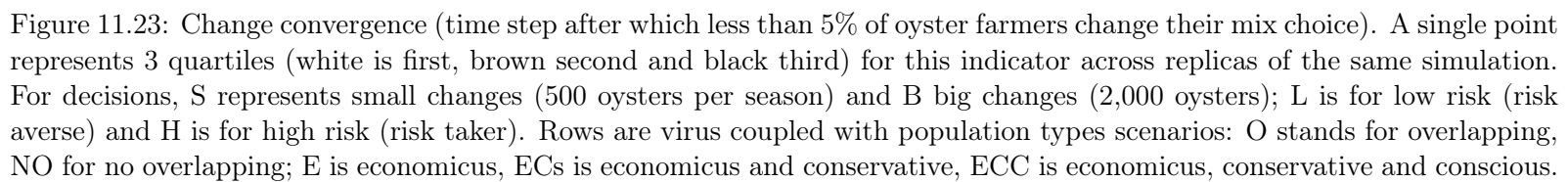


Figure 11.22: Oyster farmers choice of mixes. Tr (respectively Di and Na) stands for triploid (respectively diploid and natural) and mixes represent combinations of the previous pure choices.



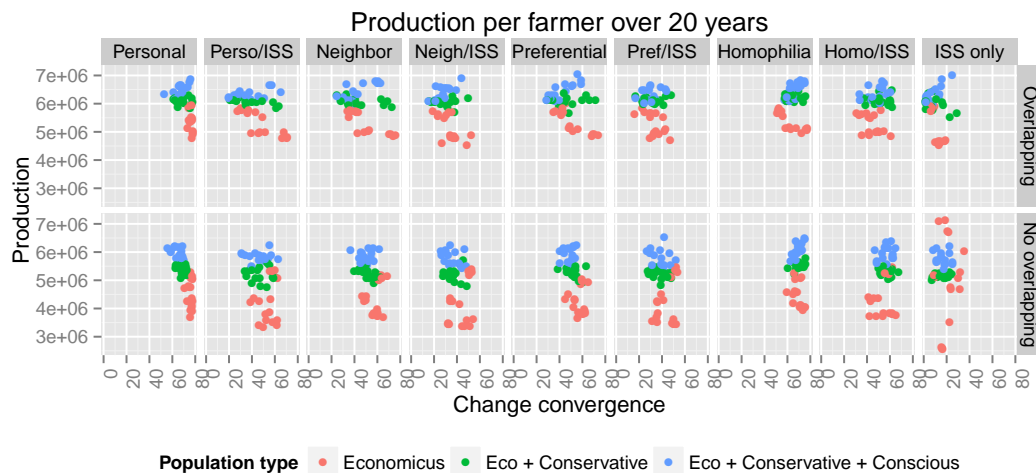


Figure 11.24: Total production as a function of change convergence.

since mortality impacts production and agent choices are production-oriented. Figure 11.24 shows total production as a function of convergence speed. In this graph, I grouped scenarios according to population ratios. When population is constituted only of “economicus”, total production is systematically lower than with the addition of other types of agents. Maximal production is obtained when the three types of agents are present. The “ISS only” situation leads to surprisingly dispersed results for “economicus” where production changes from simple to double. Observing this figure confirms that there is little difference in the model for production for the various information sharing scenarios.

11.2.3 Conclusion on results

I have observed several aspects of the simulations. First, I investigated environmental indicators: mortality rates, total number of oysters in the estuary and batch size. I used two visualizations: I plotted differences with the no information sharing (“personal”) scenario; and the differences of situations with and without ISS. Then, I observed whether agents’ beliefs converged towards one another, and towards real dynamics. Finally, I looked at agents choices. All these elements allowed to measure global consequences of information sharing scenarios for the environment, beliefs and strategy nodes of Figure 11.4. These graphs resulted from an aggregation of multiple scenarios, usually 48, replicated 40 times. Conclusions obtained on different parts of model steps are summed up in Table 11.4.

The most important effect of adding an ISS is when actors do not have access to other farmers’ experiences through social networks. In situations where

Table 11.4: Impacts of ISS implementation on the different aspects of the model.

Aspect	Consequence of ISS implementation
Production	Variable according to other networks and virus scenarios (within limits of $\pm 10\%$)
Mortality	Variable according to other networks and virus scenarios (within limits of $\pm 10\%$)
Beliefs	Increased concentration of beliefs
Distance from truth	Independent from ISS implementation, depends on other variables (population heterogeneity and decision)
Mix choice	Triploids are always preferred despite higher mortality rates and not being the best economic option (in the “overlapping” case)
Convergence speed	Always faster with an ISS

there is a social network, effects on production and mortality are negligible and do not all go in the same directions: mortality and production are increased in the “homophilia” case and are decreased in others.

As far as agents are concerned, beliefs are widespread with personal information only, are less dispersed and are systematically more concentrated when an ISS is available. The ISS allows a convergence in beliefs within agents. This convergence is not correlated with a more precise knowledge of the virus dynamics since the distance between beliefs and real virus dynamics is unchanged throughout information sharing scenarios.

Oyster farmers end by choosing mostly triploid oysters, even in the “no overlapping” case where natural oysters are more profitable whatever the quantities of oysters in batches. This convergence towards the choice of growing triploids happens faster when an ISS is implemented.

In the model, there may have not been enough possible strategies for oyster farmers to adapt. This limited range of options is a fact in real-life, making it difficult for oyster farmers to adopt practices to solve the virus threat. It is possible that sharpened knowledge can be limited to this, without possible implementation in actual practices. As explained in Section 9.2.2, p.148, when viruses hit French or Australian oyster farmers, they finally had to swap oyster species.

11.3 Conclusion

In this section, I explored possible consequences of information sharing scenarios for actors who face a private threat: a threat that affects oyster farmers (an

internal threat) and that oyster farmers can exclude themselves from. During interviews, oyster farmers raised concerns about a virulent virus that strikes oysters once a year. I decided to build an agent-based model featuring several information sharing and virus scenarios. I added other variables that needed to be integrated to the model: decision making, population size and heterogeneity.

Building the model led to unveil oyster farmers decision making schemes and constraints, paving the way to an increasingly precise understanding of choices and practices. What could be the consequences of implementing information sharing in the described situation, on the agents and on the environment?

After building the model, I performed an analysis by comparing different aspects of model outcomes by comparing information sharing scenarios in two main manners: comparison with the no information sharing scenario; and comparison with and without ISS for each network scenario. The aspects that I investigated are production, mortality and batch sizes for the environment; beliefs and distance to real virus dynamics as well as mix choice and convergence for agents.

The analysis of the model shows that the effects of ISS implementation are not clear and straightforward in all evaluation dimensions. The ISS is mostly effective when there is no other means of communication such as a social network. We can observe a convergence in beliefs without them being closer to the true virus dynamics and convergence is all the more important when an ISS is available. Shared knowledge leads to faster convergence in practices choices but not to the most profitable.

The model does not include costs of ISS development, cost of appropriation and time allocated to information sharing and interpreting by actors and is purely oriented towards analysis of a content shared by all farmers in estuaries. Even with these limits, impacts of ISS implementation are here limited and ambiguous.

Part V

Discussion



Chapter 12

Discussion

In a global context of intense pressure on natural resources, especially water and its quality, the goal of the thesis was to study possible impacts of information sharing artifacts implementation to help manage a natural resource at local levels. Intuitively, implementing such artifacts should lead to better knowledge of the resource, and thus better management by actors (even when they do not know each other) as suggested by [Young et al. \(2006\)](#).

In this document, I question this hypothesis by exploring two case studies on oyster farming. Oyster growers act in estuaries which are intrinsically open environments: the quality of their water is mostly affected by users acting outside of it. Oyster farmers are even the most demanding actors in terms of water quality: if water quality is good enough for oyster farming, then all other uses of estuarine water are guaranteed.

I conducted this research by combining methodological approaches: two case study investigation using interviews, participatory observation of meetings and study of artifacts; together with a theoretical agent-based model inspired by case studies. Studying artifacts led to identify the concept of threats: tackling them is the main reason for developing such artifacts. Thanks to this concept, I was able to explore information sharing stakes linked to the three types of threats that I have found in the case studies.

In this chapter, firstly, I critically discuss the methodology that I employed in the thesis. Then, I discuss, advantages, limits and perspectives of the concept of threats as it has been proposed in Chapter 3 and applied to the case studies. Finally, I draw lessons to learn from the outcomes regarding information sharing to deal with threats in the context of [Natural Resources Management \(NRM\)](#) and propose steps to move forward and confirm those findings.

12.1 On the methodological approach

The subject of information sharing artifacts impact on [NRM](#) is vast and several methodological approaches are possible. The method that I used consisted in investigating two different cases on oyster farming, a single and wide lagoon in France, and several estuaries in [New South Wales \(NSW\)](#). To conduct the field study, I relied on interviews and participatory observation of meetings. I used the [Social-Ecological System \(SES\)](#) framework to compare situations and spot variables that could be considered significant in explaining differences in information sharing use. Finally, to broaden the scope of the study by exploring another kind of threat than the microbiological, a threat regularly evoked by all farmers, I decided to develop an agent-based model on the herpes virus. I go through these steps with a critical approach.

12.1.1 Case studies

Two cases Choosing to study two different cases, one of which, the Australian one, involved several sub-cases, quickly enabled me to observe each case in light of the other. Spotting important variables, such as size effects, or the sense of belonging to a community, proved much easier after starting to investigate the second case (the Australian one).

Going deep into the study of specific contexts is a lengthy and time-consuming process (see next section), also a rewarding one. Misleading conclusions linked to local specificities would have prevented the identification of what I consider to be the main findings of the thesis: the identification of a subset of important variables leading to possible assertions on information sharing effects and the definition of the concept of threats.

Initially, there was a focus on OMEGA Thau that was understood as a participatory artifact that farmers could collaborate to. This system proved to be mainly developed by and for the use of local authorities. This tool has been praised as a very advanced one and the [Syndicat Mixte du Bassin de Thau \(SMBT\)](#) is known to be a proactive local council, especially regarding environmental issues. However, this tool did not prove enough to complete an investigation on how local actors may be involved in [NRM](#) using information artifacts. Except from a fraction of them being consulted during dialogue phases and being at the center of local development schemes ([SAGE-Thau, 2015](#)), Thau oyster farmers seemed to feel little responsibility for water quality, and unaware of the existence of the artifact.

The study of the Australian case led to discover [Environmental Management Systems \(EMSs\)](#), documents that emerged from the oyster industry. This fact prompted me to enlarge the scope of information sharing artifacts, and thus the scope of the thesis, to non-technological ones such as simple static text documents. Those types of artifacts could be evaluated using the ENCORE dimensions and proved to have a larger impact than the technologically-advanced

one developed in Thau. Through the development process of these artifacts, actors achieved reflexivity over the resource and their practices, confirming [Young et al. \(2006\)](#)'s intuition according to which reflexivity is an essential characteristic of adapted management.

If one is testing hypotheses in real settings, one should be aware of the importance of framing accurately the context in which the model is tested, as [Castillo et al. \(2011\)](#) warn. On the other side, when hypotheses and theories emerge from the study of specific contexts, a comparative study allows to get rid of irrelevant and misleading details, that may have been deemed important at first. The present study solely focuses on oyster farming, and stakes that I defined for information sharing may be too context-specific and could evolve with the addition of new studies.

Beyond local specificities of the present case studies, the two-case methodology that I followed proved an important step that enables switching from context-specific facts towards more general ones and favors a dialogue between cases. I studied them in order to test an initial assumption, which is one of the main use of case studies as [Poteete et al. \(2010\)](#) explain. The study of two cases allowed to limit one the drawbacks linked to conclusions that one can draw from single-case studies pointed out in [Poteete et al. \(2010\)](#): findings lack external validity. The initial assumptions that I developed regarding the role of information sharing for [NRM](#), and more specifically in the context of oyster farming, evolved greatly after investigating a second case thanks to the development of initial hypotheses that the second case infirmed. A limit while studying several cases is the "limited leverage in the analysis of cross-case variation" ([Poteete et al., 2010](#), p.36). I overcame this limitation using the [SES](#) framework as a tool for comparison. As shown in Chapter 10, information sharing has impacts ranging from more accurate previsions (Thau Lagoon) to changing mental models of most actors ([NSW](#)). The range defined by those two studies would have been limited to one side if I had not investigated two different cases.

Choices are necessary to make while studying cases due to mundane constraints such as access to field, data or people as well as time and funding. Considering these constraints, an initial study on cases that share a large amount of variables such as the cases of this thesis is a coherent choice. The experience of the process followed during this thesis leads me to advocate strongly for the study of at least two case studies before jumping to conclusions.

On the investigation of case studies In this thesis, I investigated a broad relation (between information sharing and [NRM](#)) that cannot be clarified in a definitive manner but on which assumptions are often made. A contextual focus is a perfect opportunity to question and qualify general normative statements on such relations. In order to come out with answers specific enough for actors to use practically, a focus on precise types of [SESs](#) is a perfect entry. For

Table 12.1: Organizing a case study.

Step	Expected outcome
Determine a type of SES that is subject to the problem, questions and linked hypotheses to investigate	Obtain adapted case type
Read on the general ecology of the cases as presented in Chapter 7, using the SES framework as a guide	Gain knowledge on craft
Depending on constraints (time, money, access) and opportunities (network, availability of data), identify specific cases (at least two)	Be able to start case investigation
In-depth interviews with a handful of actors, some randomly chosen and some important actors (local champion, <i>i.e.</i> someone who would be indicated by several actors as someone whose opinion matter) - possibly in a single case	Capture qualitative specific data and get new insights
Review hypotheses, make new assumptions if necessary and create a questionnaire allowing for the precise testing of these new hypotheses	Refine or shift approach of question
In-depth interviews with actors of a second case in the same manner	Get rid of elements specific to first case
Create a more precise questionnaire (or two comparable ones) allowing for the testing of these sharpened assumptions and submit it to actors of both cases	Collect quantitative data

the researcher, investigating cases is however a lengthy process. How should researchers organize their study? I would recommend to follow the steps listed in Table 12.1.

This process is an adaptation of the one that I followed for the present work that takes into account errors that I made during the thesis, leading to waste of time or interviews less productive than they could have been.

12.1.2 SES framework

The [SES](#) framework proposes an important set of variables to take into account when analyzing a system in which a human and a natural environment are coupled (Table B.1, p.260). To first get acquainted with the cases, I used reports and scientific literature to try and complete as much of the variables as possible, summarized in Table 8.3, p.137. This exercise proved useful, helped me identify knowledge gaps, especially with the main question of information

sharing, a specific type of interaction, in mind.

Completing the framework was useful and frustrating at the same time. Traditional studies on natural commons focus on systems that are relatively closed, in which the identification of boundaries are clear. Two studies helped qualifying this statement. [Brewer \(2012\)](#) discusses the question of defining clear boundaries, suggesting that keeping them open allows for more adaptive management. [Nagendra and Ostrom \(2014\)](#) study urban lakes in Bangalore, open and complex environment, with important inflows, and a loose community of actors. In the present work, completing the [SES](#) framework while focusing on oyster farming required constant choices to decide whether elements should be kept in or out of the analysis. I discussed in details consequences of boundary choice in Chapter 7, summing up the main impacts of this choice in Table 7.3, p.112: internalize all flows at the expense of increasing the number of actors, or limiting the number of actors at the cost of making most flows external? This is the price to pay while studying systems as open as the ones oyster growers act in.

An element that I developed in Section 3.3 and that structured the thesis, is that threats are usually approached differently such as in [Anderies et al. \(2004\)](#)'s robustness framework.

One of the triggering point of the study of the commons is the so-called tragedy. This tragedy occurs because of free-riding, pursuit of personal interest and eventual depletion of the common pasture. The main point in studying systems as the ones studied through the lens of [SES](#) is that they are subject to threats, originating from actors' behavior or the environmental dynamics. Describing a [SES](#) situation without explicitly pointing out threats to researchers and actors is an major flow in the framework. I proposed in Table 3.6, p.40, a set of variables that would help identifying important threats while studying a [SES](#).

Despite these limitations, the [SES](#) framework was a useful and helpful guide to structure the study of such complex systems. The assumed complexity of the considered systems prevents an analysis in terms of focusing on an element under constraint of the other, rather taking into account interactions between elements.

The [SES](#) framework proved to be more than a guide for study. As mentioned in the previous section, the framework is a useful tool to enable broad comparison of cases on a vast number of variables. Splitting the variables into a set of common variables (such as in Table 7.1, p.106) and of potentially different variables allowed to refine the comparison and to identify variables that can make a difference for the question under scrutiny.

12.1.3 Agent-based modeling

Developing the model The agent-based model that I developed was the most challenging part of the thesis. After having interviewed farmers, and

after seeing the *Oyster Information Portal* that gathers information about mortality and growth, I decided to develop a model to see whether collective information sharing on a virus threat could help actors learn and understand better environmental dynamics and subsequently make appropriate decisions. The choice of developing the model is linked to the intrinsic difficulty of following information sharing, in real settings, as much in terms of participation in a system as interpretation of obtained information. It is also linked to the time frame: the virus acts only once a year, and studies in epidemiology are not reproducible (Bonté, 2011).

As cited in Chapter 6, according to Minsky (1968, p.1), “to an observer B , an object A^* is a model of an object A to the extent that B can use A^* to answer questions that interest him about A .” In the present case, I am the observer (and the reader is) and the agent-based model is a model of oyster farmers facing a virus situation that was designed to help answering questions about the impact of information sharing: can information help agents to adapt to this private threat?

Setting up the different information sharing modalities was natural: no sharing, sharing through a network and through a technological system, with possible combinations. On the other hand, deciding over types of information to share and cognitive interpretation of received information has been a difficult phase. The possible scope of interpretation was limited and the range of possible choices decided by actors is small: they have to choose a mix between three species and quantities. In real cases, farmers do not have many other possibilities: they can choose to diversify their activity (by growing other shellfish species, by fishing, or opening a restaurant); or try natural oysters which apparently, according to a farmer who strictly grows natural oysters, are not affected by the virus (in the model, natural oysters are affected).

The way the model is coded does not allow for personal complex interpretation of information: agents receive information (figures), aggregate them using probabilities and follow a set of pre-established rules that allow them to make a decision regarding the next season. Other more or less complex solutions for information sharing and aggregation could have been considered, as in Pyka et al. (2007) who model the use of information with a capability/ability/expertise triplet that evolves with research and experimentation. The virus context did not favor such a complex way of modeling information since options are limited for agents: they can only change oyster types and quantities. On the contrary, simpler representations seemed most logical, especially when considering real-life applications such as the *Oyster Information Portal* developed by Nash and Rubio-Zuazo (2012) and lessons learned that simple quantitative information seemed the most useful to oyster farmers.

The other variables that I tested (decision type, population size and constitution) came with conceptual model development and resulted in an important number of scenarios which made it tricky to explore in-depth. Global comparison of results required either aggregation that gums out variations, or creation

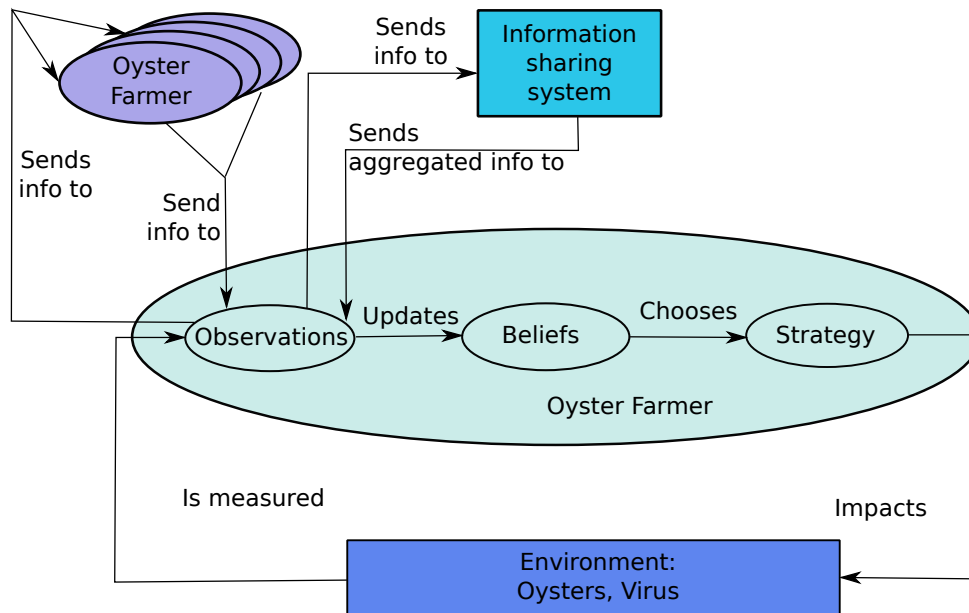


Figure 12.1: Main loop of the model (reproduced).

of exotic representations.

Possible extensions The model code is designed in a modular way that makes evolutions as easy as possible. For instance, information shared is treated separately from decision-making. Several extensions are possible and can be considered. As a reference, I reproduced Figure 11.4 that I follow to suggest further exploration. Each verb associated with an arrow or noun with a box in the figure is the result of an algorithm or a representation choice that can always be questioned and changed.

Initialization During the initialization, farmers all have the same budget, batch size and beliefs. Other initialization parameters are possible. Those easy to implement variations could lead the system to other directions than those observed with the parameters presented in the document.

Virus dynamics As it is, other and more complicated virus dynamics may be explored. Numerous virus models are listed in Gilligan (2002) that are useful for inspiration. A major change would be to choose to explore the last type of threat that has not been considered in this thesis: the common threat. The virus can easily be modeled as a common threat rather than a private one. However, switching this modification would shift the main question from private learning thanks to a collection of collective experiments to self-regulating capability of agents. Mortality would be a function of the

total number of oysters in the estuary, rather than independent draws of the virus at the scale of single batches or tables.

Information (sharing) What could be the result of a erroneous model A^* that cannot represent accurately the environmental dynamics? In the model, the collected and shared information allows to describe and understand the virus dynamics as long as enough information is given to the system. The virus dynamics may be linked to variables that are not collected and thus the information shared could be misconceived, or only partly reflect the virus *modus operandi*. In the model, with m corresponding to the mortality function, we have $m = m(qty, type)$. Both qty and $type$ are shared among farmers. Local variations could be added and not taken into account, $m = m(qty, type, location)$, with only qty and $type$ being shared.

Decision making I opted for a simple modeling choice where actors follow simple rules. I defined three types of agents who have various goals and follow different procedures. According to their own experiences and their network, they receive heterogeneous values for mortality and use the same model of the virus dynamics to make their decisions for the next season. Heterogeneity is thus linked to information received and type of agents. For a given type of agent and a given stimuli (here information received), there is a single deterministic decision d at time step n : $d_n = d(agentType, information, d_{n-1})$. However, the observed outcomes led to averaged behaviors that made it difficult to distinguish among them and identify and track interesting trajectories. Instead of creating such agents, one could imagine agents with various response threshold, *e.g.* a threshold above which they change their production type. The threshold embodies various interpretations of the same information that allows to include reasoning elements that cannot be taken into account in the model (a type of white noise). I expect from this strategy to increase heterogeneity among agents and favor a wider diversity of outcomes.

On the use of ABMs Creating an agent-based model enabled another type of evaluation of information sharing role for actors than with the use of the ENCORE framework. This method enables a quantitative tracking of evolutions of facets difficult to identify, or simply observe, in real settings thanks to the creation of a model that one can tweak and master: evolution of beliefs, knowledge, practices and environment.

These facets allow to qualify consequences of information sharing in this model and of other elements in other models. Replication of experiences and controlled variations of scenarios is a strong benefit of agent-based models and simulations. Changes in the situation are difficult to track since events are non reproducible (such as viruses attacking oysters) and are delayed in time (the virus attacks only once a year) and changes are subtle to observe

in actors minds and practices (since changes may be due to other causes than the one under focus). This situation advocates strongly for agent-based model development and simulation.

However, exploring a model is a time-consuming task. In this model, only 6 variables have been kept (Table 11.3, p.183) which, once combined, led to 1300 scenarios. This number of scenarios is already the result of drastic down-sizing in terms of variables or values. This fact leads to necessary compromises between a thorough exploration of all the simulations using an aggregation with the risk of gumming out interesting differences or a finer one but rapidly difficult to handle. The evolutions suggested above even increase the number of scenarios and make exploration even more complex. It is possible to counter this effect by giving fixed values to variables that do not lead to noticeable effects in the analysis, such as the “decision-making” variable in the model.

The exploration strategy that I followed in the thesis is a useful one when a model includes a large number of variables. I suggest the following steps:

1. After defining a set of simple indicators, draw aggregated graphs along various dimensions to get first insights on which global effects can appear by using representations along time.
2. Use these graphs to create global indicators which were not considered initially, such as “change convergence”. These indicators should capture a scenario with a single number, not a time series.
3. Identify a subset of scenarios that seem interesting or leading to varying outcomes and explore them again in more details using the indicators used for the first two steps.

12.2 On threats in SESs

12.2.1 Goods

The typology of goods presented in Chapter 2 (Table 2.1, p.13) introduces two dimensions, subtractability and excludability. These dimensions allow for a definition of four types of goods or resources: public, private and club goods, as well as common-pool resources.

By creating this typology, a set of specific and effective questions was linked to each good type. First, since common-pool resources are highly subtractable and difficult to exclude, issues such as depletion and free-riding emerge. [Ostrom \(1990\)](#) found necessary rules linked to specificity of issues for common-pool resources management (Table 2.4, p.17). Second, public goods are difficult, if not impossible, to exclude and not subtractable. The main issues associated with this type of goods are its provision and free-riding. How to ensure that enough means (money, time) are allocated to the provision of the good? Third, club goods, highly excludable and not subtractable, are also

subject to the question of provision. In this case, the possibility of exclusion makes it easier to prevent free-riding. Private goods are out of the scope of such a theory, except when they are tied together through another type of good.

Using this typology to frame a question and a situation is an effective manner of considering problems that may emerge, and provides directions to look for so as to solve or tackle such problems.

12.2.2 Threats

Threats so far The typology of goods opens explicit roads for investigation, but it does not provide a way to fit threats that are commonly faced by actors and communities while belonging to the [NRM](#) realm: floods, pests, epidemics, pollution, exhaustion, free-riding among others. It could be possible to frame a flood as a public good provision problem as [Carlson et al. \(2015\)](#) do, the provision consisting in privately implementing diverse measures to limit collective (and thus private) damages. Even though the threat can fit within the previous typology, it feels awkward to consider a flood as a public good, at least semantically. This flood should be considered a threat, a threat for a set of actors, wreaking havoc on a number of characteristics of goods and resources of various types (private homes, public facilities ...).

The threat typology that I exposed in Chapter 3 proposes an operational formalization of threats with the $\langle \mathcal{A}, \mathcal{C}, I, D, E \rangle$ tuple: a set of actors \mathcal{A} is concerned for characteristics of assets \mathcal{C} , characterized by infrastructure I , human decisions D and environmental dynamics E . Threats can be organized along two dimensions.

First, the internality dimension determines whether the threat affects other actors than the (potentially self-constituted) set of actors \mathcal{A} . Determining this property helps concerned actors to choose whether they should try to reach outside their own community. A threat recognized as non-internal threat should prompt actors of \mathcal{A} to define a strategy that reaches external actors, as did oyster farmers in the Australian case, for instance, by sharing information. Second, the excludability dimension is defined on the solution side: can a solution adopted by a single actor be effective or should it be collective. In some cases, collective action is compulsory. The tragedy of the commons emerges from this fact. In some other cases, actors may decide which to consider the threat as excludable or not. In Thau Lagoon, oyster farmers need to depurate oysters before selling them. All farmers decided to build depuration basins in their own sheds while collective basins could have been built. Actors have played an important part in choosing how to deal with a threat. The choice they make is a projection of how they consider a threat.

Determining these two dimensions combined with the case studies allowed to identify three main types of threats: public, common and private. There is still an empty space in the typology for little internal and highly excludable

threats that does not specifically appeared in the case studies but which may emerge from other types of cases, where actors are less intrinsically linked by a common resource such as water in the case of oyster farming.

I developed this typology to be operational. A group of actors can use this classification to define strategies to tackle threats. Australian oyster farmers developed their EMSs with this idea in mind. By showing clearly how external actors impacted their activity and the environment using an information sharing artifact, these actors managed to impact upstream actors and local councils practices. As shown in Chapters 10 and 11, where I investigate information sharing systems as infrastructure to deal with examples of public and private threats, giving a type to a threat leads to a specific approach (Section 12.3). The internality dimension was inspired by the case study and I added the excludable one that bears consequences for information sharing stakes.

A common vision of threats is an essential part of devising solutions that are accepted by all (Adams et al., 2003), as much as shared mental models of SESSs (Castillo Brieva, 2013). I defined the typology with the goal of creating a meaningful classification of threats for actors such as the internal / external one developed in EMSs. The time frame of a thesis did not allow me to test this. In order to gain legitimacy and be reinforced or modified, the concept should now be experimented with actors.

The future of threats For the moment, due to the angle adopted in the thesis, I characterized information sharing stakes linked to each type of threat (see Section 12.3) and explored the two least investigated of them. The concept of threats emerged during the research from the study of a specific type of interaction, information sharing, out of a set of possible interactions, such as self-organizing and evaluative activities, listed in the SES framework. Considering other types of interactions could be a way to make the threat typology more robust and potentially see general patterns and strategies available to actors emerge, such as those that appeared from the classification of goods in Ostrom et al. (1994).

Mental models A question that emerges from such a framing of a NRM situation is that of the mental models of actors. What does foster more collaboration: uniting behind a collective threat or a collective framing of shared resources? The case studies considered in this thesis, especially the French one, show that oyster farmers see each other as competitors in good times and unite when they collectively face a threat, at least in the case of the public threat. This observation provides a first insight, but is not sufficient to conclude on the question.

Dynamics A second element that requires investigation is the dynamic side of threats, especially in the case of excludable threats. The theory could go further by trying to understand what could be the externalities caused by some actors adopting individual solutions. A solution that is adopted by a single individual may mitigate a threat for the person while increasing the threat for other actors. A collective solution may better address the threat for a larger group of actors. The importance of collective projects to frame threats and discuss strategies together is a possible important prove important in these situations. Does classifying threats according to the typology make actors changing the considered solutions?

Evaluation Threats are characterized as $T = \langle \mathcal{A}, \mathcal{C}, I, D, E \rangle$. They potentially limit the capability of actors in \mathcal{A} to take advantage of assets due to a deterioration of characteristics \mathcal{C} of the asset. Endowing threats with a structure could increase the operational potential of the concept while leading to promising theoretical questions in collective decision aiding. For instance, one could model the deterioration using a capability function $c_{\mathcal{A}}$ that depends on actors and enrich threats by giving them a structure that includes consequences and possible defenses \mathbb{D} . For instance, defenses may be actions on I or D ; or on information on E and may thus be thought using the formalism. Information sharing artifacts are examples of such a defense: creating a piece of infrastructure I that could influence decisions D . Such a model offers a possible way to evaluate threats and considered solutions. Developing the concept in this direction requires cautious generalization of concepts drawn from the capability approach developed in [Sen et al. \(1999\)](#) which is focused on individuals and not on groups.

Conclusion The elements on threats provided and developed in this thesis create the core of a formalism that could be effectively used by actors and which has to be tested further. I proposed the threat typology as a way complementary to the goods and resources typology to address core questions in [NRM](#). This concept provides a new possible focal almost orthogonal to goods and resources: all types of asset characteristics may have to face all types of threats (Table [3.5](#), p.37). Elements regarding threats are absent from the [SES](#) framework, while they are central for [NRM](#). Threats, under the form proposed in Table [3.6](#), p.40, should be added to the [SES](#) framework.

12.3 On information sharing artifacts for NRM

Throughout the thesis, I considered information sharing artifacts as pieces of infrastructure destined at tackling various threats. First, I critically recall the hypotheses of information sharing stakes associated with the different types of threats under the light of the case studies and the model. Then, I go through

what I consider to be the advantages and limits of these artifacts that I can justify thanks to the present research, proposing complementary manners to explore further these claims.

12.3.1 Information sharing artifacts to face threats

Characterizing threats opened the door to a clear delimitation of information to seek for, in terms of environmental dynamics, infrastructure and decision-making. Using these variables allows actors to precisely define what is known and what is not, identifying what it is, and researching for what is not.

The case studies, based on a group of actors acting in an environment where inflows are independent from actors and of core importance to them, allowed me to identify three types of threats. Those threats point out various strategic directions for information sharing artifacts.

Public threats - Influencing Oyster farmers (\mathcal{A}) are located downstream of catchment areas. They are heavily dependent on good water quality and have to face regular microbiological peaks (E), leading to bans on sells, due to upstream activities, practices (D) or facilities (I). For oyster farmers, this is a case of public threat. I claimed that in this situation, information sharing artifact implementation, a new piece of infrastructure I , is mostly used to gain clout over future developments and as members of communities.

In the Australian case, building EMSs proved a way to effectively gain influence and change decisions D of upstream actors, by working as a coherent group of actors, hand in hand with local authorities. The industry is increasingly seen as responsible for water quality management, slowly becoming stewards over this resource. By listing a long set of internal threats, that, on a close look, include only few that could improve water quality, they have managed to show how responsibly they act. In this case, oyster farmers managed to gain influence over upstream actors, convincing them as well as the global community of the role of all in water quality.

In the French case, the main artifact that I studied, OMEGA Thau, has been initiated by public authorities. To French oyster farmers, the microbiological threat is also a public threat. Communication with upstream actors is done through local oyster farming lobbies and public authorities. The information sharing artifact is here a technical tool, little known by oyster farmers, that assists local authorities in predicting short term flows as well as long term changes due to developments. As a side effect, oyster farmers have a more precise information regarding microbiological flows and possible bans on sells. According to most actors that I interviewed, the supplementary information that they could get from the system did not appeal them, appearing as slightly better than weather forecast. If we take the point of view of oyster farmers, the system does not produce information that makes a difference. In the long run however, due to strong regulatory constraints on water quality

(*e.g.* [WFD, 2012](#)), the precise model that has been obtained in the information sharing artifact should serve oyster farmers.

The cases propose two visions of how information sharing artifacts may be used to manage a public threat. On the one hand, artifacts and their implementation allows actors to gain power and influence, increasingly becoming stewards of the resource they need. On the other hand, artifacts are tools that finely monitor flows and subsequently inform actors, without farmers even being aware of the existence of the artifact.

Private threats - Learning Being attacked by a virus (E), oysters farmers (A) face an internal threat. In the thesis, I considered the threat as a private one. The main question linked to private threats is how to escape the threat, or simply limit its effects, by choosing an adapted solution, *i.e.* making a right decision D? If there is perfect knowledge, then the best solution should be chosen by all. However, perfect knowledge does not exist, and a bounded rationality is a preferable assumption, especially since there would be no point in implementing information sharing artifacts. I investigated how the way information is shared could influence how actors learned the virus dynamics through an agent-based model. The model leads to contrasted conclusions. Different facets of the model can be evaluated to compare scenarios in a quantitative manner, especially the influence of information sharing means availability, through personal experience, networks and/or a centralized information sharing system. In this context, the more information is shared, the more agents share a set of beliefs (in the model, on oyster mortality rates) but there is no connexion with proximity of knowledge to the truth (*i.e.* real virus dynamics) that actors do not manage to achieve. Production is slightly influenced by information sharing, but heterogeneity of agents seems to be the most important factor to determine the production.

Common threats - Monitoring I did not specifically examine the last type of threat, the common one, on the case studies. The common threat is the usual threat that [Common-pool resources \(CPRs\)](#) face. I claimed that facing this type of threat requires an information sharing to monitor users decisions, ensuring conditional cooperation. The examples that I found in the literature confirm this hypothesis. Monitoring the resource may be a solution for actors, but it can lead to faster depletion as demonstrated in [Haynie et al. \(2009\)](#). A study focusing on information sharing for this type of threat has yet to be conducted and may be started by studying further the rich literature on this type of threat.

Conclusion Defining different types of threats allowed a precise delimitation of information sharing artifacts requirements and goals addressed to specific types. Within the limited time frame of a thesis, I had the opportunity to

investigate different types of artifacts linked to two types of threats. The study of other artifacts in similar contexts, for instance oyster farming in the United States, where environmental processes are advanced, or in other areas of France could complement the present study. To be able to draw more general conclusions, it could be useful to investigate other types of [SEs](#) where actors have developed information sharing artifacts and see whether the goal in creating them fits with the stakes considered here. The framework that was developed during the course of the thesis now provides testable hypotheses.

12.3.2 General findings on information sharing artifacts

Apart from those stakes, information sharing artifacts generate effects that go beyond their content. An artifact creation may lead to a common perception on issues and an external representation around which actors may refer to. Artifacts come with limits that may prevent them from being used, or even to be useful.

Advantages One of the important effects that Australian oyster farmers kept evoking is the evolution of the mental model of the [SE](#) they act in, as shown using the ENCORE framework that allows qualitative tracking of changes (Chapter 10). Creating [EMS](#) led oyster farmers to all gather in regular meetings organized by an external facilitator, during which they had the opportunity to discuss their vision of their activity, their practices, the surrounding environment, and threats they have to deal with. During the process, actors who did not know each other came to discover others. The oyster farming community as a whole became more cohesive and stronger thanks to the participatory process that led to the artifacts creation.

I intended to investigate deeper the idea that the creation process is fundamental for the success or failure of an artifact by looking at the French case, through a survey. The survey failed to be launched to a wide audience of oyster farmers. The few people who answered complained about a lack of general information on the existence of artifacts, except those who were directly involved in creating the artifacts. The survey does not allow me to conclude further, but these initial elements seem to confirm the hypothesis. The link between creation, appropriation and future use has to be explored further. [Elster \(2010\)](#) provides a framework in the context of collective decision processes relating actors (those who are effectively in the process) and subjects (those who will be affected by the decision) that can be used as a base for exploration.

Creation is important, what about the use? When the artifact is supposed to reach external actors, it can be considered as a boundary object, accessible to all, with different meanings and uses. A global document such as an [EMS](#) enables communication between different types of actors, even without the presence of the other. A more technical tool such as OMEGA Thau is not conceived as an interface between several worlds, even though it can be used

for this purpose: promoters may understand better consequences on water quality of their projects, oyster farmers are informed more precisely, public authorities follow flows better. Once again, the ENCORE framework allows to keep track of those possible evolutions in various parts of the community thanks to an evaluation on six qualitative dimensions.

Limits As evoked in the previous paragraph, the mere existence of an artifact, even with a well-defined goal, even with a goal that would serve actors, is not enough to ensure that it is known, accepted, trusted or used. In France, few actors were aware of the existence of OMEGA Thau, and even less of the existence of the French version of an EMS, written by an intern who interviewed a handful of public servants and oyster farmers. Few were aware of the existence of a beautifully made guide summing up techniques, rules and regulations destined to oyster farmers (Gervasoni et al., 2011).

Even a well-thought process such as the one described for EMS implementation does not systematically lead to shared mental models that enable going beyond profound divergent beliefs. In Wapengo Lake, even though an EMS was developed in 2010, some growers applied for triploid Pacific Oyster *Crassostrea Gigas* (PO) cultivation approval, while (diploid) PO is considered a pest in NSW. This created a rift amongst farmers, and communication is currently non-existent.

When well-designed, information sharing artifacts increase knowledge and reflexivity of actors on their environment. However, they cannot foresee everything. The example of farmers in the Hawkesbury River who implemented an EMS and improved the local situation, participating in reaching pristine water quality, working hand in hand with local authorities and the surrounding community, and who were struck by the herpes virus that wiped them out for the second time in less than 10 years illustrates this idea.

If we think of actors implementing information sharing artifacts to influence others' practices, then support of public authorities seems necessary. In the Australian case study, even though I did not have the opportunity to visit farmers located in the North Coast, success of EMS implementation was more nuanced than in the South. In the North Coast, local public agencies lacked fundings to support farmers. On the other hand, farmers were less proactive in developing their EMSs.

12.3.3 Information sharing artifacts for NRM

In the case studies, the main resource to be managed is water. Water quality is of importance to oyster farmers, fishermen as well as for the whole community. Oyster farmers have the highest requirement regarding water quality for their activity. Public servants have legal quality levels to meet, defined by rules and regulations.

In the thesis, I have studied different approaches of information artifacts use to manage a natural resource. The first one based on the coupling of simple documents, one issued by public authorities, [Oyster Industry Sustainable Aquaculture Strategy](#) (OISAS, 2006, 2014), and one developed by oyster farmers, EMSs. In this low-tech approach, external representation asserted and lobbied for the role of oyster farmers as stewards of the resource, being though of as sentinels of the environment, with an increasing acceptance by the rest of the community. The main goal is to make mental models evolve around the idea of collective responsibility on water management.

Information sharing artifacts are not enough by themselves to modify actors' representations and practices. Collective sense of stewardship through the use of artifacts can be achieved through an involving process, and not only with their mere existence. As a French oyster farmer puts it: "first, we need to talk to each other." Creating an artifact may be a good pretext for such a dialogue. In this manner, it can probably be asserted that the information produced is a difference that can make a difference: the information sought for comes from grassroots demand and is therefore considered useful, for themselves or for external actors.

In the French case, public authorities have implemented a costly and long to develop technology-laden artifact that enables a fine and high level vision of the catchment, especially water flows. Being considered central and sensitive actors, oyster farmers are overrepresented in local decision instances and dialogue sessions and are considered beneficiaries of information generated by the artifact. However, they did not originate the project and the artifact hardly fosters an evolution of mental representations and a sense of collective responsibility. This example provides a case of information sharing artifact that leads to differences for public authorities and little difference for oyster farmers.

The information sharing artifact in the model is an example that does not lead to much difference for actors on performances when other means of information sharing exist, as the social networks in the model. These differences are even strongly affected by existing social networks. Worse, the artifact leads to convergence of beliefs of agents on the environmental dynamics (actually a more cohesive collective mental model) tracked by the system but not to beliefs closer to the true virus dynamics. Effects of information in this case may be so limited that in the end actors might have to change completely their growing techniques, an option unavailable in the model.

Those three examples lead to divergent conclusions on the difference created by information sharing artifacts: efficient, neutral, ambiguous. The results obtained support the diversity of results observed in the literature and are a step towards a refinement of the relation between information sharing and NRM. Implementing information artifacts as infrastructure to face threats should be considered with care since they are long and costly (even though these elements have not been studied here) to develop with uncertain results. The existence of other means to share information (Table 4.4, p.55) should

also be taken into account since they may provide differences that would gum out the potential difference brought by the artifact.

Chapter 13

Conclusion

- Dove va l'umanità?
- Boh!

Uccellacci e uccellini

Pier Paolo Pasolini

13.1 Findings

Context and method In this thesis, I have investigated the link between collective [NRM](#) and information sharing, through the study of specific artifacts in the context of oyster farming and, more generally, coastal water management. The research led me to question the positive correlation generally associated between artifacts existence and improvements in collective resource management and to find ways to evaluate this correlation.

To conduct the study, I have explored two main cases, the Thau Lagoon, France and several estuaries in [NSW](#), Australia. Actors in those places face comparable conditions for their production and devise and use, in various ways, more or less technologically advanced information artifacts. In addition to the study of real cases, I developed an exploratory agent-based model based on those cases.

Evaluating the role of information sharing for natural resources management first prompted to decompose the notion of information sharing artifacts through content (what), medium (how) and goal (why). The main information artifacts that I found in the cases were oriented towards coping with threats (a goal) using various media (from simple text documents to technologically advanced systems) and contents (from arguments to models). I evaluated information sharing artifacts consequences using two methods: a quantitative one with the use of an agent-based model that enabled the tracking of various dimensions; and a qualitative one through the ENCORE framework that allowed to go beyond content. These two methods are ways to understand the

(potential) difference created by artifacts for actors that could be impacted by new information availability.

Main results In this paragraph, I recall the take-home messages of this thesis.

On methods An empirical approach based on a case study investigation proved a valuable method to explore the main questions of the thesis regarding consequences of information sharing artifacts for [NRM](#). The [SES](#) framework that guided and structured the exploration of cases created a path for investigation that enabled to quickly grasp those cases globally and precisely at the same time, without forgetting important elements of those complex systems.

Since the question of the thesis is open and complex, exploring a single case would have led to misleading conclusions due to local particularities. Thus, even considering the time-frame of a thesis, a two-case study investigation is a minimum to be able to get rid of local specificities and adopt a wider and more nuanced view on the question.

The [SES](#) framework is useful to describe the cases but does not provide a method for understanding focal systems dynamics. The use of the ENCORE framework and an agent-based model provided ways to more efficiently measure, as much qualitatively as quantitatively, and study evolutions linked to information sharing artifacts implementation.

On threats Framing oyster farmers questions under the lens traditionally used of goods and resources coupled with associated dilemmas (free-riding, provision) did not prove efficient in this case. The main artifacts that I studied are aimed at tackling or understanding microbiological flows in the surrounding catchment so as to guarantee water quality. Water quality is a public good that cannot be provided for. The study of information sharing artifacts content led to understand the importance of threats around which collective action is organized.

The $\langle \mathcal{A}, \mathcal{C}, I, \mathcal{D}, \mathcal{E} \rangle$ model of threats allows actors to identify the main elements that characterize threats: infrastructure, human decisions and environmental dynamics. The two dimensions of internality and excludability enable to define strategies for actors to cope with it, as much in terms of information sharing (the focus of this document) as others. Framing the oyster farming situation in this context was easier and more natural. The concept of threat is likely to be applied to a large set of [SES](#) situations.

Threats are a complementary way to the goods and resources vision to describe a [SES](#). They allow to understand related stakes and need to be explicitly kept in mind while studying such a system. Actors facing public threats need to devise ways to reach the cause or find manners to make decisions that influence infrastructure or others' decisions. Actors facing private threat need

to understand the said threat to deal with it. Finally, actors dealing with a common threat have to forge institutions to force all to adopt practices that would ensure sustainability use of the resource. In this regard, threats are a catalyst for collective action.

On information sharing The study of various information sharing artifacts, whether real or theoretical, and the evaluation of consequences for actors using ENCORE or an agent-based model is a step towards an extension of knowledge of the relation between information sharing and NRM. I list some lessons that can be drawn from this study. As a reminder, since the approach is descriptive and not normative, it is not possible to derive theorems from it:

- Information sharing may lead to important differences: the Australian case provided an example of actors who fostered collective action by creating a low-tech artifact that legitimized them as stewards of the resource they depend on and smoothed relations with all surrounding actors. This case is a case of positive correlation between information sharing, sustainable NRM and collective action.
- Information sharing may lead to little changes: the French case provided an example of artifact that is mostly technical and makes little difference to actors on a day-to-day basis. Indeed, information given by the model does not make more precise predictions than those that weather forecasts allow to deduce, at least according to oyster farmers.
- More technology does not necessarily lead to more impact: evaluation of Australian and French artifacts using the ENCORE framework led to demonstrate a wider impact of simple documents on water management, on mental models and on relations than the more technology advanced one.
- The existence of information artifacts is not enough: the creation process needs to be carefully thought for the artifact to be known, or used. This point is strongly linked to the previous one. Implication of actors in the process is fundamental since participation is what creates most changes.
- Information sharing artifacts may be used to face threats: actors can use information to reach upstream actors whose activities impact them; they can also use artifacts to favor collective learning, even though, in the model, this approach did not prove successful.

The present research does not allow me to conclude on absolute necessary properties required for information sharing artifact to lead to more sustainable management of resources, or better handling of threats actors deal with, since it is based on similar case studies. However, they allow to precise the frontier

between information artifacts that have an impact and those that do have a limited one. I strongly recommend the use of the ENCORE framework for qualitative assessment, or of an agent-based model for a more quantitative one of differences made by information artifacts, since they may be long and costly to produce for uncertain results.

13.2 Future research

The notion of threats needs to be investigated further if the notion is to be associated with strategies, as for the different types of goods and resources. I have investigated and characterized information sharing stakes linked to threats but information sharing is but a possible interaction between actors of a [SES](#). Three directions seem to me the most interesting to expand knowledge on this notion: explore new [SES](#) types; structure and evaluate threats and explore other types of interactions.

Firstly, there is a need for the study of common threats which were not investigated in this thesis due to unadapted [SESSs](#). Furthermore, other cases may reveal the importance and relevance of the non-internal and excludable threat that did not appear in the present case studies.

Secondly, this thesis is a first step in the theoretical study of threats. Endowing threats with a proper evaluation method of consequences and possible defense mechanisms, such as the one using capability theory sketched in the previous chapter, would be a step towards a stronger and possibly more effective theory.

Finally, information sharing artifacts implementation is but a possible interaction between actors of a [SES](#). The study of other types of interactions is a way to study the threats typology's robustness. For instance, are specific types of threats tackled by similar monitoring activities in various [SESSs](#)?

13.3 Epilogue

Managing natural resources is a difficult task, as shown by the diversity of questions asked, studies conducted and ways devised by local communities to deal with this fundamental element intrinsically linked to the future of mankind. This task is difficult due to the range of uncertainties, of individual decision making, of beliefs, of usages made out of these resources. We now have to face an uncertain future of an era sometimes called the anthropocene, where the influence of man is predominant, leading to climate change and trespassing of planetary boundaries. The intertwining of environmental, social and economic spheres are to take into account with now an increasing focus made on the environment.

Numerous examples have shown that local communities are able to create institutions that enable sustainable management of social-ecological systems,

i.e. systems mostly defined by the interaction between actors, resources and rules defining a space of possibilities. The emergence of information technologies and the turn taken by society towards the use of information for an immense variety of purposes obliges us to think of the possible implications of information sharing at local levels for [NRM](#).

While creating the information sharing artifacts for his community, Bob has discovered that the artifacts that will influence most actors' practices and mental models and eventually the resource are not necessarily those which are technologically advanced. During the implementation process, he realized that the existence of a collective project was already a sign of possible convergence in problem formulation and solution seeking; that is was an opportunity to make allies of local authorities and work with other categories of actors.

However, he also realized that there is no simple link between the existence of information sharing artifacts and efficient resource management. Knowledge does not necessarily lead to avoiding threats. Improvements in environment situation can only be reached thanks to long term adoption of sustainable practices that may be difficult to attain, all the more so if other unaware actors are implied.

In this context, communication and alliances between different spheres of actors interacting around a [SES](#) is essential. Oyster farmers call themselves, and are called by others, sentinels of the environment. Indeed, they are those who need the best water quality. The inclusion of all in an environment all feel responsible for can be fostered by the creation of information sharing artifacts, or other types of information sharing processes. Farmers testimonies of these processes show how influential these are, more than the mere information that can be found in a specific artifact. Information sharing processes do not necessary need to be built around artifacts, but can be imagined using all types of processes favoring the emergence of social connections and ecological values.

Bibliography

- Abadie, E., Belsher, T., Dérolez, V., Fiandrino, A., Guillou, J.-L., Lemsanni, A., Loubersac, L., Pastoureaud, A., Sérais, O., Vercelli, C., and Troussellier, M. (2004). Synthèse de connaissances acquises sur la lagune de Thau et son bassin versant (France). Technical report, Ifremer.
- Achard, F., Beuchle, R., Mayaux, P., Stibig, H. J., Bodart, C., Brink, A., Carboni, S., Desclée, B., Donnay, F., Eva, H. D., Lupi, A., Raši, R., Seliger, R., and Simonetti, D. (2014). Determination of tropical deforestation rates and related carbon losses from 1990 to 2010. *Global Change Biology*, 20(8):2540–2554.
- Acheson, J. M. (1975). The lobster fiefs: Economic and ecological effects of territoriality in the maine lobster industry. *Human Ecology*, 3(3):183–207.
- Acheson, J. M. (2003). *Capturing the commons: devising institutions to manage the Maine lobster industry*. Upne.
- Ackoff, R. L. (1989). From data to wisdom. *Journal of applied systems analysis*, 16:3–9.
- Adams, W. M., Brockington, D., Dyson, J., and Vira, B. (2003). Managing tragedies: understanding conflict over common pool resources. *Science (New York, N.Y.)*, 302(5652):1915–6.
- Adriaans, P. (2013). Information. In Zalta, E. N., editor, *The Stanford Encyclopedia of Philosophy*. Fall 2013 edition.
- Aker, C. J. (2008). “Can You Hear Me Now?” How Cell Phones are Transforming Markets in Sub-Saharan Africa. *Center for Global Development*, (202):3.
- Alexander, S. M. (2015). *The ties that bind: Connections, patterns, and possibilities for marine protected areas*. PhD thesis, Waterloo, Ontario, Canada.
- Allen, W. and Kilvington, M. (2005). Getting technical information into watershed decision-making. In Hatfield, J., editor, *The Farmers’ Decision: Balancing Economic Successful Agriculture Production with Environmental Quality*, pages 45–61. Soil and Water Conservation Society.

- Amblard, F. and Quattrociocchi, W. (2013). Social Networks and Spatial Distribution. In Edmonds, B. and Meyer, R., editors, *Simulating Social Complexity*, chapter 16, pages 401–430. Springer Berlin Heidelberg, Berlin Heidelberg.
- An, L. (2012). Modeling human decisions in coupled human and natural systems: Review of agent-based models. *Ecological Modelling*, 229:25–36.
- Anderies, J. M. (2006). Robustness, institutions, and large-scale change in social-ecological systems: the Hohokam of the Phoenix Basin. *Journal of Institutional Economics*, 2(02):133.
- Anderies, J. M., Janssen, A. M., Bousquet, F., Cardenas, J.-C., Castillo, D., Lopez, M.-C., Tobias, R., Volla, B., and Wutich, A. (2011). The challenge of understanding decisions in experimental studies of common pool resource governance. *Ecological Economics*, 70(9):1571–1579.
- Anderies, J. M., Janssen, A. M., and Ostrom, E. (2004). A framework to analyze the robustness of social-ecological systems from an institutional perspective. *Ecology and Society*, 9(1).
- Anderies, J. M. and Janssen, M. A. (2013). *Sustaining the commons*. Center for the study of institutional diversity, Temple, Arizona, arizona st edition.
- Anwar, S. M., Jeanneret, C. A., Parrott, L., and Marceau, D. J. (2007). Conceptualization and implementation of a multi-agent model to simulate whale-watching tours in the St. Lawrence Estuary in Quebec, Canada. *Environmental Modelling and Software*, 22(12):1775–1787.
- Apesteguia, J. (2006). Does information matter in the commons?. Experimental evidence. *Journal of Economic Behavior and Organization*, 60(1):55–69.
- Archibald, S., Staver, A. C., and Levin, S. A. (2012). Evolution of human-driven fire regimes in Africa. *Proceedings of the National Academy of Sciences*, 109(3):847–852.
- Aven, T., Renn, O., and Rosa, E. A. (2011). On the ontological status of the concept of risk. *Safety Science*, 49(8-9):1074–1079.
- Axelrod, R. and Hamilton, W. D. (1981). The evolution of cooperation. *Science*, 211(4489):1390–1396.
- Barabási, A.-L. and Réka, A. (2002). Statistical mechanics of complex networks. *Reviews of Modern Physics*, 74(January):48–94.
- Barreteau, O., Bousquet, F., Millier, C., and Weber, J. (2004). Suitability of multi-agent simulations to study irrigated system viability: application to case studies in the senegal river valley. *Agricultural Systems*, 80(3):255–275.

- Barreteau, O., Le Page, C., and Perez, P. (2007). Contribution of simulation and gaming to natural resource management issues: An introduction. *Simulation & Gaming*, 38(2):185–194.
- Bateson, G. (1972). *Steps to an ecology of mind: Collected essays in anthropology, psychiatry, evolution, and epistemology*. University of Chicago Press.
- Bell, A. R., Shah, M. A. A., Anwar, A., and Ringler, C. (2015). What role can information play in improved equity in Pakistan ’s irrigation system ? Evidence from an experimental game in Punjab. *Ecology and Society*, 20(1).
- Berger, C., Romani, M., Sourribes, V.-C., and Barral, M. (2007). Recueil des bonnes pratiques environnementales en conchyliculture. Technical report, Pôle relais lagunes méditerranéennes, Espaces naturels de France, Office de l’environnement de la Corse, Montpellier, France.
- Berkes, F. and Folke, C. (1998). Linking social and ecological systems for resilience and sustainability. Technical report.
- Berkes, F. and Jolly, D. (2001). Adapting to Climate Change : Social-Ecological Resilience in a Canadian Western Arctic Community. *Conservation ecology*, 5(2).
- Bhaskar, R., Frank, C., Hoyer, K. G., Naess, P., Parker, J., Change, C., Realism, S., Emancipation, H., and Reality, R. (2010). *Interdisciplinarity and Climate Change. Transforming knowledge and practice for our global future*, volume 1st.
- Binder, C. R., Hinkel, J., Bots, P. W. G., and Pahl-wostl, C. (2013). Comparison of Frameworks for Analyzing Social-ecological Systems. *Ecology and Society*, 18(4).
- Bodin, Ö. and Crona, B. I. (2009). The role of social networks in natural resource governance: What relational patterns make a difference? *Global Environmental Change*, 19(3):366–374.
- Bodin, O., Crona, B. I., and Ernstson, H. (2006). Social networks in natural resource management: what is there to learn from a structural perspective? *Ecology And Society*, 11(2):r2.
- Bodin, Ö. and Prell, C. (2011). *Social networks and natural resource management: uncovering the social fabric of environmental governance*. Cambridge University Press.
- Bommel, A. P., Page, C. L., Bécu, N., and Bousquet, F. (2012). A Cormas model from scratch step by step : the ECEC model.

- Bommel, P. (2009). *Définition d'un cadre méthodologique pour la conception de modèles multi-agents adaptée à la gestion des ressources renouvelables*. PhD thesis, Université Montpellier II.
- Bonté, B. (2011). *Modélisation et simulation de l'interdépendance entre l'objet, l'observateur et le modèle de l'objet dans la Triade de Minsky. Application à la surveillance épidémiologique en santé animale*. PhD thesis, Université Montpellier II.
- Bousquet, F., Bakam, I., Proton, H., and Page, C. L. (1998). Cormas: Common-pool resources and multi-agent systems. *Tasks and Methods in Applied Artificial Intelligence*, pages 826–837.
- Bousquet, F. and Le Page, C. (2004). Multi-agent simulations and ecosystem management: A review. *Ecological Modelling*, 176(3-4):313–332.
- Bray, D. and von Storch, H. (1999). Climate science: An empirical sample of postnormal science. *Bulletin of the American Meteorological Society*, 80(3):439–455.
- Brewer, J. F. (2012). Don't Fence Me In: Boundaries, Policy, and Deliberation in Maine's Lobster Commons. *Annals of the Association of American Geographers*, 102(January 2013):383–402.
- Brocard, G., Derolez, V., Serais, O., Fiandrino, A., Lequette, C., Lescoulier, C., Benedetti, M., Couton, P., and Marty, D. (2010). OMEGA Thau: outil de management environnemental et de gestion de l'avertissement des pollutions microbiologiques du bassin de Thau. Technical report, Ifremer, SMBT, Egis Eau, BRL, Sète.
- Bryant, E. (2014). *Tsunami: the underrated hazard*. Springer.
- Buchanan, J. M. and Stubblebine, W. C. (1962). Externality. *Economica*, 29(116):371–384.
- Buller, H. (1996). Towards sustainable water management: Catchment planning in France and Britain. *Land Use Policy*, 13(4):289–302.
- Bunders, J. F., Broerse, J. E., Keil, F., Pohl, C., Scholz, R. W., and Zweekhorst, M. B. (2010). How can transdisciplinary research contribute to knowledge democracy? In *Knowledge Democracy*, pages 125–152. Springer.
- Butt, D. and Raftos, D. (2007). Immunosuppression in Sydney rock oysters (*Saccostrea glomerata*) and QX disease in the Hawkesbury River, Sydney. *Marine and Freshwater Research*, 58(2):213–221.
- Cameron, A. and Crane, M. (2011). International OsHV-1 μ Var Workshop, Cairns, Queensland, Australia 9-10 July 2011. Technical Report July, Fisheries Research and Development Corporation, Canberra.

- Carlson, C., Barreteau, O., Kirshen, P., and Foltz, K. (2015). Storm Water Management as a Public Good Provision Problem : Survey to Understand Perspectives of Low-Impact Development for Urban Storm Water Management Practices under Climate Change. *Journal of Water Resources Planning Management*, 04014080(13):1–13.
- Castells, M. (2011). *The rise of the network society: The information age: Economy, society, and culture*, volume 1. John Wiley & Sons.
- Castillo, D., Bousquet, F., Janssen, M. A., Worrapimphong, K., and Cardenas, J. C. (2011). Context matters to explain field experiments: Results from Colombian and Thai fishing villages. *Ecological Economics*, 70(9):1609–1620.
- Castillo Brieva, D. (2013). *Arrangements institutionnels et modèles mentaux dans la gestion des ressources en bien commun*. PhD thesis, Université Paris Ouest Nanterre La Défense.
- Ceptralmar (2007). Plaquette de présentation du Ceptralmar. Technical report, Ceptralmar.
- Ceptralmar (2008). Guide de l'exploitation conchylicole en Languedoc-Roussillon. Technical report, Ceptralmar.
- Chaudhary, P., Chhetri, N. B., Dorman, B., Gegg, T., Rana, R. B., Shrestha, M., Thapa, K., Lamsal, K., and Thapa, S. (2015). Turning conflict into collaboration in managing commons: A case of Rupa lake watershed, Nepal. *International Journal of the Commons*, 9(2):744–771.
- Chaudhuri, A. and Paichayontvijit, T. (2006). Conditional cooperation and voluntary contributions to a public good. *Economics Bulletin*, 3(8).
- Collins, E., Lawrence, S., Pavlovich, K., and Ryan, C. (2007). Business networks and the uptake of sustainability practices: the case of New Zealand. *Journal of Cleaner Production*, 15(8-9):729–740.
- Conway, J. (1970). The game of life. *Scientific American*, 223(4):4.
- Cotoc, E. A., Traistaru, A., and Stoica, A. (2013). Systems of Environmental Management. *European Journal of Humanities and Social Sciences*, 25(1):1316–1325.
- Cox, M., Arnold, G., and Villamayor, S. (2010). A Review of Design Principles for Community-based Natural Resource Management. *Ecology and Society*, 15(4):28.
- Crona, B. and Bodin, Ö. (2006). What You Know is Who You Know ? Communication Patterns Among Resource Users as a Prerequisite for Co-management. *Ecology And Society*, 11(2):7.

- Crowley, T. J. (2000). Causes of Climate Change Over the Past 1,000 Years. *Science (New York, N.Y.)*, 289(5477):270–277.
- Cutts, B., White, D., and Kinzig, A. (2011). Participatory geographic information systems for the co-production of science and policy in an emerging boundary organization. *Environmental Science & Policy*, 14(8):977–985.
- Dalcanale, F., Fontane, D., and Csapo, J. (2011). A General Framework for a Collaborative Water Quality Knowledge and Information Network. *Environmental Management*, 47(3):443–455.
- Daniell, K. A. (2012). *Co-engineering and participatory water management: organisational challenges for water governance*. Cambridge University Press.
- Daniell, K. A. and Barreteau, O. (2014). Water governance across competing scales: Coupling land and water management. *Journal of Hydrology*, 519:2367–2380.
- Daniell, K. A., White, I., Ferrand, N., Ribarova, I. S., and Coad, P. (2010). Co-engineering Participatory Water Management Processes : Theory and. *Ecology And Society*, 15(4):11.
- David, N. (2013). Validating simulations. In Edmonds, B. and Meyer, R., editors, *Simulating Social Complexity*, chapter 8. Springer Berlin Heidelberg, Berlin Heidelberg.
- Day, J. W., Crump, B. C., Kemp, W. M., and Yáñez Arancibia, A. (2013a). *Estuarine Ecology*. Wiley-Blackwell, Hoboken, New Jersey, second edition.
- Day, J. W. D. J., Alejandro, Y., and Kemp, W. M. (2013b). Human Impact and Management of Coastal and Estuarine Ecosystems. In Day, J. W. J., Crump, B. C., Kemp, W. M., and Yanez-Arancibia, A., editors, *Estuarine Ecology*, chapter 19, pages 483–495. Wiley-Blackwell, Hoboken, New Jersey, second edition.
- Day, J. W. J., Yanez-Arancibia, A., Kemp, W. M., and Crump, B. C. (2013c). Introduction To Estuarine. In Day, J. W. J., Crump, B. C., Kemp, W. M., and Yanez-Arancibia, A., editors, *Estuarine Ecology*, chapter 1, pages 1–18. Wiley-Blackwell, Hoboken, New Jersey, second edition.
- Deltreil, J. P. (1973). Evolution et conséquence de la mortalité de *C. angulata* dans le bassin d’Arcachon et l’estuaire de la Gironde de 1971 à 1973. Technical report, CIEM-Conseil International pour l’Exploration de la Mer.
- Deslous-Paoli, J. M., Souchu, P., Mazouni, N., Juge, C., and Dagault, F. (1998). Relations milieu-ressources: Impact de la conchyliculture sur un environnement lagunaire Méditerranéen (Thau). *Oceanologica Acta*, 21(6):831–843.

- Dunster, K. (2011). *Dictionary of natural resource management*. UBC Press.
- Edmonds, B. and Meyer, R. (2013a). Introduction to the Handbook. In Edmonds, B. and Meyer, R., editors, *Simulating Social Complexity*, chapter 1, pages 3–11. Springer Berlin Heidelberg, Berlin Heidelberg.
- Edmonds, B. and Meyer, R. (2013b). *Simulating Social Complexity*. Springer.
- Edwards, V. and Steins, N. (1999). Special issue introduction: the importance of context in common pool resource research. *Journal of Environmental Policy & Planning*, 1(3):195–204.
- El-Sayed, A. M., Scarborough, P., Seemann, L., and Galea, S. (2012). Social network analysis and agent-based modeling in social epidemiology. *Epidemiologic Perspectives & Innovations*, 9(1):1.
- Elster, J. (1989). Social Norms and Economic Theory. *Journal of Economic Perspectives*, 3(4):99–117.
- Elster, J. (2010). Rationalité et sciences sociales. *L'annuaire du Collège de France. Cours et travaux*, (109):583–601.
- EMSTilligerry (2014). Tilligerry Creek Port Stephens - EMS. Technical report, Tilligerry Creek Oyster Farmers.
- EMSWagonga (2012). Wagonga Inlet Oyster Farmers - EMS. Technical report, Wagonga Inlet Oyster Farmers.
- Evans, K. S. and Weninger, Q. (2013). Information Sharing and Cooperative Search in Fisheries. *Environmental and Resource Economics*, 58(3):353–372.
- Evenson, R. E. and Gollin, D. (2003). Assessing the Impact of the Green Revolution, 1960 to 2000. *Science*, 300(5620):758–762.
- Fairweather, P. G. (1999). Determining the ‘health’ of estuaries: Priorities for ecological research. *Austral Ecology*, 24(4):441–451.
- FAO (2001). *Crassostrea Gigas*. Technical Report 8, Food and Agriculture Organization of the United Nations.
- Ferber, J. (1999). *Multi-agent system*. Pearsons, United Kingdom, 1 edition.
- Fernandes, P. G. and Cook, R. M. (2013). Reversal of fish stock decline in the northeast atlantic. *Current Biology*, 23(15):1432–1437.
- Ferrand, N. (2004). ‘encore’ un modèle d’analyse, intervention et questions. Technical report, Cemagref, Montpellier, France.

- Fertig, B., Carruthers, T., Dennison, W., Fertig, E., and Altabet, M. (2010). Eastern oyster (*Crassostrea virginica*) $\delta^{15}\text{N}$ as a bioindicator of nitrogen sources: Observations and modeling. *Marine Pollution Bulletin*, 60(8):1288–1298.
- Fertig, B., Carruthers, T. J. B., and Dennison, W. C. (2014). Oyster delta N-15 as a Bioindicator of Potential Wastewater and Poultry Farming Impacts and Degraded Water Quality in a Subestuary of Chesapeake Bay. *Journal of Coastal Research*, 30(5):881–892.
- Fioretti, G. (2013). Agent-based simulation models in organization science. *Organizational Research Methods*, pages 1–25.
- Fischbacher, U., Gächter, S., and Fehr, E. (2001). Are people conditionally cooperative? Evidence from a public goods experiment. *Economics Letters*, 71(3):397–404.
- Flood, M. M. (1958). Some experimental games. *Management Science*, 5(1):5–26.
- Folke, C., Hahn, T., Olsson, P., and Norberg, J. (2005). Adaptive Governance of Social-Ecological Systems. *Annual Review of Environment and Resources*, 30(1):441–473.
- Fowler, M. (2004). *UML distilled: a brief guide to the standard object modeling language*. Addison-Wesley Professional.
- Funtowicz, S. and Ravetz, J. (2003). Post-Normal Science. *Ecological Economics*, (Feb):1–10.
- Gangnery, A., Chabirand, J. M., Lagarde, F., Le Gall, P., Oheix, J., Bacher, C., and Buestel, D. (2003). Growth model of the Pacific oyster, *Crassostrea gigas*, cultured in Thau Lagoon (Méditerranée, France). *Aquaculture*, 215(1-4):267–290.
- Gervasoni, E., Perignon, A., Sourisseau, E., and Lagarde, F. (2011). Monographie La conchyliculture en Méditerranée. Technical report, Ifremer, Sète.
- Gervasoni, E. and Ritter, L. (2014). commercialisation Etat des lieux et impact pour la profession conchylicole. Technical report, Cephalmar.
- Gibson, J. J. (1978). The ecological approach to the visual perception of pictures. *Leonardo*, pages 227–235.
- Gietzelt, A., Keating, J., and Davies, H. (2014). Oysters - an aphrodisiac for engaging industry and coastal communities in sustainable estuary management. In *Coastal Conference*, pages 1–14, Ulla Dulla.

- Gilligan, C. a. (2002). *An epidemiological framework for disease management*, volume Volume 38.
- Giovannoni, V. (1995). *Les pêcheurs de l'étang de Thau: écologie humaine et ethnologie des techniques*. l'Harmattan.
- Girard, S., Agundez, J., Gangnery, A., and Vornière, J. (2010). Impact of Cultural Practices on the individual and Collective Economic Performances in Shellfish Farming: the Case of Oyster Farming in Baie Des Veys. In *IIFET 2010 Montpellier Proceedings*, pages 1–12.
- Girard, S. and Pérez Agúndez, J. a. (2014). The effects of the oyster mortality crisis on the economics of the shellfish farming sector: Preliminary review and prospects from a case study in Marennes-Oleron Bay (France). *Marine Policy*, 48:142–151.
- Golub, B. and Jackson, M. O. (2010). How Homophily Affects the Speed of Contagion , Best Response and Learning. *Learning*, (February):1–58.
- Gotts, N., Polhill, J., and Law, A. (2003). Agent-based simulation in the study of social dilemmas. *Artificial Intelligence Review*.
- Griffin, K. et al. (1974). The political economy of agrarian change, an essay on the green revolution. *The political economy of agrarian change, an essay on the green revolution*.
- Grimm, V., Berger, U., Bastiansen, F., Eliassen, S., Ginot, V., Giske, J., Goss-Custard, J., Grand, T., Heinz, S. K., Huse, G., Huth, A., Jepsen, J. U., Jørgensen, C., Mooij, W. M., Müller, B., Pe'er, G., Piou, C., Railsback, S. F., Robbins, A. M., Robbins, M. M., Rossmanith, E., Rüger, N., Strand, E., Souissi, S., Stillman, R. a., Vabø, R., Visser, U., and DeAngelis, D. L. (2006). A standard protocol for describing individual-based and agent-based models. *Ecological Modelling*, 198(1-2):115–126.
- Grimm, V., Berger, U., DeAngelis, D. L., Polhill, J. G., Giske, J., and Railsback, S. F. (2010). The ODD protocol: A review and first update. *Ecological Modelling*, 221(23):2760–2768.
- Grimm, V., Polhill, G., and Touza, J. (2013). Documenting Social Simulation Models: The ODD Protocol as a Standard. In Edmonds, B. and Meyer, R., editors, *Simulating Social Complexity*, chapter 7, pages 117–133. Springer Berlin Heidelberg, Berlin Heidelberg.
- Grizel, H. and Héral, M. (1991). Introduction into France of the Japanese oyster (*Crassostrea gigas*). *Journal du Conseil: ICES Journal of Marine Science*, 47(3):399–403.

- Guo, X., DeBrosse, G. a., and Allen, S. K. (1996). All triploid Pacific oyster (*Crassostrea gigas* Thunberg) produced by mating tetraploids and diploids. All-triploid Pacific oysters (*Crassostrea gigas*). *Aquaculture*, 142(3-4):149–161.
- Gutiérrez, N. L., Hilborn, R., and Defeo, O. (2011). Leadership, social capital and incentives promote successful fisheries. *Nature*, 470(7334):386–389.
- Hardin, G. (1968). The tragedy of the commons. *Science (New York, N.Y.)*, 162:1243–1248.
- Haynie, A. C., Hicks, R. L., and Schnier, K. E. (2009). Common property, information, and cooperation: Commercial fishing in the Bering Sea. *Ecological Economics*, 69(2):406–413.
- Henry, A. D. and Dietz, T. (2011). Information, networks, and the complexity of trust in commons governance. *International Journal of the Commons*, 5(2):188–212.
- Hernán, M. a. (2010). The hazards of hazard ratios. *Epidemiology (Cambridge, Mass.)*, 21(1):13–5.
- Hess, C. and Ostrom, E. (2003). Ideas, artifacts, and facilities: Information as a common-pool resource. *Law and Contemporary Problems*, 66.
- Hillary, R. (2004). Environmental management systems and the smaller enterprise. *Journal of Cleaner Production*, 12(6):561–569.
- Jack, B. K. (2009). Upstream–downstream transactions and watershed externalities: Experimental evidence from Kenya. *Ecological Economics*, 68(6):1813–1824.
- Jackson, M. O. et al. (2008). *Social and economic networks*, volume 3. Princeton University Press Princeton.
- Jackson, M. O. and López-Pintado, D. (2013). Diffusion and contagion in networks with heterogeneous agents and homophily. *Network Science*, 1(01):49–67.
- Janssen, M. and Ostrom, E. (2006). Empirically based, agent-based models. *Ecology and Society*, 11(2).
- Janssen, M. a. (2013). The Role of Information in Governing the Commons: Experimental Results. *Ecology and Society*, 18(4).
- Janssen, M. a., Bousquet, F., and Ostrom, E. (2012). Dossier « Le champ des commons en question : perspectives croisées » - A multimethod approach to study the governance of social-ecological systems. *Natures Sciences Sociétés*, 19(4):382–394.

- Janssen, M. a., Holahan, R., Lee, A., and Ostrom, E. (2010). Lab experiments for the study of social-ecological systems. *Science (New York, N.Y.)*, 328(5978):613–7.
- Janssen, M. A. and Ostrom, E. (2014). Vulnerability of Social Norms to Incomplete Information. In Xenitidou, M. and Edmonds, B., editors, *The Complexity of Social Norms*, pages 161–173. Springer International Publishing, Cham.
- Kirsh, D. (2010). Thinking with external representations. *AI and Society*, 25(4):441–454.
- Kocher, M. G., Cherry, T., Kroll, S., Netzer, R. J., and Sutter, M. (2008). Conditional cooperation on three continents. *Economics Letters*, 101(3):175–178.
- Lansing, J. S. (1991). Priests and programmers.
- Lansing, J. S. (2009). *Priests and programmers: technologies of power in the engineered landscape of Bali*. Princeton University Press.
- Le Page, C., Bazile, D., Becu, N., Bommel, P., Etienne, M., Mathevet, R., and Weber, J. (2013). Agent-based modelling and simulation applied to environmental management. In Edmonds, B. and Meyer, R., editors, *Simulating Social Complexity*, Understanding Complex Systems, chapter 19, pages 499–540. Springer Berlin Heidelberg, Berlin, Heidelberg.
- Le Page, C., Becu, N., Bommel, P., and Bousquet, F. (2012). Participatory Agent-Based Simulation for Renewable Resource Management : The Role of the Cormas Simulation Platform to Nurture a Community of Practice. *Journal of Artificial Societies and Social Simulation*, 15:10.
- Li, J., Michael, H. A., Duke, J. M., Messer, K. D., and Suter, J. F. (2014). Behavioral response to contamination risk information in a spatially explicit groundwater environment: Experimental evidence. *Water Resources Research*, 50(8):6390–6405.
- Lindenmayer, D. B., Margules, C. R., and Botkin, D. B. (2000). Indicators of biodiversity for ecologically sustainable forest management. *Conservation Biology*, 14(4):941–950.
- Macal, C. M. and North, M. J. (2010). Tutorial on agent-based modelling and simulation. *Journal of Simulation*, 4(3):151–162.
- Mackay, D. J. C. (2003). *Information Theory, Inference and learning algorithms*. Cambridge University Press, Cambridge, seventh edition.

- Mangra, M. G., Cotoc, E. A., and Traistaru, A. (2014). Sustainable economic development through environmental management systems. *Journal of Studies in Social Sciences*, 6(1):1–14.
- Marean, C. W. (2015). The most invasive species of all. *Scientific American*, 313(2):32–39.
- Massoud, J. a., Daily, B. F., and Bishop, J. W. (2011). Perceptions of environmental management systems. *Industrial Management & Data Systems*, 111(1):5–19.
- Maurel, P. (2012). *Signes, Données et Représentations Spatiales: Des éléments de sens dans l'élaboration d'un projet de territoire intercommunal. Application au territoire de Thau*. PhD thesis, Université du Sud Toulon Var.
- McCarthy, J. J., Canziani, O. F., Leary, N. A., Dokken, D. J., and White, K. S. (2001). *Climate change 2001: impacts, adaptation, and vulnerability*. Cambridge University Press, Cambridge, United Kingdom, 1st edition.
- McGinnis, M. D. (2011). An Introduction to IAD and the Language of the Ostrom Workshop: A Simple Guide to a Complex Framework. *Policy Studies Journal*, 39(1):169–183.
- McGinnis, M. D. and Ostrom, E. (2014). Social-ecological system framework: Initial changes and continuing challenges. *Ecology and Society*, 19(2).
- Meyn, A., Taylor, S. W., Flannigan, M. D., Thonicke, K., and Cramer, W. (2010). Relationship between fire, climate oscillations, and drought in British Columbia, Canada, 1920–2000. *Global Change Biology*, 16(3):977–989.
- Minsky, M. L. (1968). Matter, Minds and Models. In *Semantic Information Processing*, pages 425–432.
- Mongrue, R., Vanhoutte-Brunier, A., Fiandrino, A., Valette, F., Ballé-Béganton, J., Pérez Agúndez, J. a., Gallai, N., Derolez, V., Roussel, S., Lample, M., and Laugier, T. (2013). Why, how, and how far should microbiological contamination in a coastal zone be mitigated? An application of the systems approach to the Thau lagoon (France). *Journal of environmental management*, 118:55–71.
- Müller, B., Bohn, F., Dreßler, G., Groeneveld, J., Klassert, C., Martin, R., Schlüter, M., Schulze, J., Weise, H., and Schwarz, N. (2013). Describing human decisions in agent-based models - ODD+D, an extension of the ODD protocol. *Environmental Modelling and Software*, 48:37–48.

- Nagendra, H. and Ostrom, E. (2014). Applying the social-ecological system framework to the diagnosis of urban lake commons in Bangalore , India. *Ecology and Society*, 19(2).
- Narukawa, Y. (2007). *Modeling decisions: information fusion and aggregation operators*. Springer Science & Business Media.
- Nash, C. and Rubio-Zuazo, A. M. (2012). Monitoring the canaries of our catchments. In *21st NSW Coastal Conference*.
- Newell, R. I. E. (2004). Ecosystem influences of natural and cultivated populations of suspension-feeding bivalve molluscs: a review. 23:51–61.
- Nikolai, C. and Madey, G. (2009). Tools of the trade: A survey of various agent based modeling platforms. *Journal of Artificial Societies and Social ...*, 12(2).
- Nishitani, K. (2010). An Empirical Analysis of the Effects on Firms' Economic Performance of Implementing Environmental Management Systems. *Environmental and Resource Economics*, 48(4):569–586.
- Norling, E., Edmonds, B., and Meyer, R. (2013). Informal Approaches to Developing Simulation Models. In Edmonds, B. and Meyer, R., editors, *Simulating Social Complexity*, chapter 4, pages 39–55. Springer Berlin Heidelberg, Berlin Heidelberg.
- NSWDEC (2005). Marine water quality objectives for NSW ocean waters. Technical report, Department of Environment and Conservation (NSW), Sydney.
- NSWDPI (2013). Aquaculture in New South Wales - Facts and Figures 2013. Technical report, NSW Department of Primary Industries, Sydney.
- NSWDPI (2014). Aquaculture Production Report 2013 - 2014. Technical report, NSW Department of Primary Industries, Sydney.
- NSWFA (2014). Marine Biotoxin Management Plan. Technical report, NSW Food Authority, Sydney.
- OceanWatch (2014). The role of natural resources management in the NSW oyster industry. Technical report, OceanWatch, Australian Government, LLS Greater Sydney, Sydney.
- Oden, E., Martenot, C., Berthaux, M., Travaillé, E., Malas, J. P., and Houssin, M. (2011). Quantification of ostreid herpesvirus 1 (OsHV-1) in *Crassostrea gigas* by real-time PCR: Determination of a viral load threshold to prevent summer mortalities. *Aquaculture*, 317(1-4):27–31.

- OED (2015). *The Oxford English Dictionary*. Oxford University Press.
- OISAS (2006). NSW Oyster Industry Sustainable Aquaculture Strategy. Technical report, NSW Department of Primary Industries.
- OISAS (2014). NSW Oyster Industry Sustainable Aquaculture Strategy Second edition — 2014. Technical report, NSW Department of Primary Industries.
- Ostrom, E. (1990). *Governing the commons: The evolution of institutions for collective action*. Cambridge university press.
- Ostrom, E. (2007a). A diagnostic approach for going beyond panaceas. *Proceedings of the National Academy of Sciences of the United States of America*, 104(39):15181–15187.
- Ostrom, E. (2007b). Institutional rational choice: An assessment of the institutional analysis and development framework.
- Ostrom, E. (2009). A general framework for analyzing sustainability of social-ecological systems. *Science (New York, N.Y.)*, 325(5939):419–22.
- Ostrom, E. (2014). Collective action and the evolution of social norms. *Journal of Natural Resources Policy Research*, 6(4):235–252.
- Ostrom, E., Gardner, R., and Walker, J. (1994). *Rules, games, and common-pool resources*. University of Michigan Press.
- Paerl, H. W. and Justic, D. (2013). Estuarine Phytoplankton. In Day, J. W. J., Crump, B. C., Kemp, W. M., and Yanez-Arancibia, A., editors, *Estuarine Ecology*, chapter 4, pages 85–110. Wiley-Blackwell, Hoboken, New Jersey, second edition.
- Paget, N., Daniell, K. A., Rubio-Zuazo, A., and Barreteau, O. (2016). Environmental information sharing: a means to support the legitimization of oyster farmers’ stewardship over water quality management in nsw, australia? *Natural Resources Forum*.
- Paul-Pont, I., Dhand, N. K., and Whittington, R. J. (2013). Influence of husbandry practices on OsHV-1 associated mortality of Pacific oysters *Crassostrea gigas*. *Aquaculture*, 412-413:202–214.
- Pernet, F., Barret, J., Le Gall, P., Corporeau, C., Dégremont, L., Lagarde, F., Pépin, J., and Keck, N. (2012). Mass mortalities of Pacific oysters *Crassostrea gigas* reflect infectious diseases and vary with farming practices in the Mediterranean Thau lagoon, France. *Aquaculture Environment Interactions*, 2(3):215–237.

- Pernet, F., Lagarde, F., Jeannée, N., Daigle, G., Barret, J., Le Gall, P., Quere, C., and D'orbcastel, E. R. (2014). Spatial and temporal dynamics of mass mortalities in oysters is influenced by energetic reserves and food quality. *PloS one*, 9(2):e88469.
- Peterson, M. (2009). *An introduction to decision theory*. Cambridge University Press.
- Phillips, D. J. H. and Yim, W. W.-S. (1981). A Comparative Evaluation of Oysters, Mussels and Sediments as Indicators of Trace Metals in Hong Kong Waters. *Marine Ecology*, 6:285–293.
- PortSète (2013). Plaquette du port de Sète. Technical report, Port de Sète, Sète.
- Poteete, A. R., Janssen, M. A., and Ostrom, E. (2010). *Working together: collective action, the commons, and multiple methods in practice*. Princeton University Press.
- Poundstone, W. (2011). *Prisoner's dilemma*. Anchor.
- Pritchard, D. W. (1967). What is an estuary: Physical viewpoint. In *Estuaries*, pages 3–5. American Association for the Advancement of Science, Washington, D.C.
- Psomas, E. L., Fotopoulos, C. V., and Kafetzopoulos, D. P. (2011). Motives, difficulties and benefits in implementing the ISO 14001 Environmental Management System. *Management of Environmental Quality: An International Journal*, 22(4):502–521.
- Purnomo, H. and Guizol, P. (2006). Simulating forest plantation co-management with a multi-agent system. *Mathematical and Computer Modelling*, 44(5-6):535–552.
- Pyka, A., Gilbert, N., and Ahrweiler, P. (2007). Simulating knowledge-generation and distribution processes in innovation collaborations and networks. *Cybernetics and Systems: An International Journal*, 38(7):667–693.
- R Core Team (2015). *R: A Language and Environment for Statistical Computing*. R Foundation for Statistical Computing, Vienna, Austria.
- Rabalais, N. N., Turner, R. E., and Wiseman, W. J. (2002). Gulf of Mexico Hypoxia, A.K.A. “The Dead Zone”. *Annual Review of Ecology and Systematics*, 33(1):235–263.
- Ralha, C. G., Abreu, C. G., Coelho, C. G. C., Zaghetto, A., Macchiavello, B., and Machado, R. B. (2013). A multi-agent model system for land-use change simulation. *Environmental Modelling and Software*, 42:30–46.

- Rayssac, N., Pérignon, A., Le Gall, P., Gervasoni, E., Pernet, F., and Régler, D. (2011). Production de naissain d'huîtres en Méditerranée. Technical report, PRONAMED 2010.
- Regulation, F. and Code, F. S. (2010). NSW Shellfish Industry Manual. Technical report, NSW Shellfish Program within NSW Food Authority.
- Renn, O. (2005). White paper on risk governance, towards an integrative approach. Technical report, International Risk Governance Council, Geneva, Switzerland.
- Risvoll, C., Fedreheim, G. E., and Sandberg, A. (2014). Does Pastoralists' Participation in the Management of National Parks in Northern Norway Contribute to Adaptive Governance ? *Ecology and Society*, 19(2).
- Rommetveit, K., Funtowicz, S., and Strand, R. (2010). Knowledge, democracy and action in response to climate change. *Interdisciplinarity and climate change: transforming knowledge and practice for our global future*. New York: Routledge, pages 149–63.
- Ronnenberg, S. K., Graham, M. E., and Mahmoodi, F. (2011). The important role of change management in environmental management system implementation. *International Journal of Operations & Production Management*, 31(6):631–647.
- Rosas, I., Baez, A., and Belmont, R. (1983). Oyster (*Crassostrea virginica*) as indicator of heavy metal pollution in some lagoons of the gulf of Mexico. *Water, Air, and Soil Pollution*, 20(2):127–135.
- Rouchier, J. (2013). Agent-Based Simulation as a Useful Tool for the Study of Markets. In Edmonds, B. and Meyer, R., editors, *Simulating Social Complexity*, chapter 23, pages 617–650. Springer Berlin Heidelberg, Berlin Heidelberg.
- Rowley, J. (2007). The wisdom hierarchy: representations of the DIKW hierarchy. *Journal of Information Science*, 33(2):163–180.
- RStudio Team (2012). *RStudio: Integrated Development Environment for R*. RStudio, Inc., Boston, MA.
- Rustagi, D., Engel, S., and Kosfeld, M. (2010). Conditional cooperation and costly monitoring explain success in forest commons management. *Science (New York, N.Y.)*, 330(6006):961–5.
- SAGE-Thau (2015). SAGE des bassins versants de la lagune de Thau et de l'étang d'Ingril. Technical Report 1, Syndicat Mixte du Bassin de Thau, Sète.

- Sapolsky, R. and Balt, S. (1996). Reductionism and variability in data: A meta-analysis. *Perspectives in biology and medicine*, 39(2):193–203.
- Schelling, T. (1978). Micromotives and macrobehavior.
- Schelling, T. C. (1971). Dynamic models of segregation. *Journal of mathematical sociology*, 1(2):143–186.
- Schelling, T. C. (2006). *Micromotives and macrobehavior*. W. W. Norton and Company, revised edition.
- Schindler, D. W. and Vallentyne, J. R. (2008). *The Algal Bowl: Overfertilization of the World's Freshwaters and Estuaries*. University of Alberta Press.
- Schlager, E. and Ostrom, E. (1992). Property-Rights Regimes and Natural Resources: A Conceptual Analysis. *Land economics*, 68(3):249–262.
- Schmidt, V. A. (2007). *Democratizing France: The political and administrative history of decentralization*. Cambridge University Press.
- Schroback, P. (2015). *Economic analysis of Australia's Sydney Rock Oyster industry*. PhD thesis, Queensland University of Technology.
- Schroback, P., Pascoe, S., and Cogan, L. (2014). Socio-economic determinants for industry development : the case of Australia's Sydney rock oyster industry. *Aquatic living resource*, 27:167–175.
- Sécolier, P. (2009). *Pratiques professionnelles, enjeux territoriaux et changement social: l'évolution et la mutation des petits métiers de l'étang de Thau*. EME.
- Sen, A. et al. (1999). Commodities and capabilities. *OUP Catalogue*.
- Shannon, C. E. and Weaver, W. (1959). *The mathematical theory of communication*. University of Illinois Press.
- Shoham, Y. (1993). Agent-oriented programming. *Artificial Intelligence*, 60(1):51–92.
- Shumway, S. E. (2011). *Shellfish aquaculture and the environment*. John Wiley & Sons.
- Simon, H. A. (1976). From substantive to procedural rationality. In *25 Years of Economic Theory*, pages 65–86. Springer.
- Simon, H. A. (1982). *Models of bounded rationality: Empirically grounded economic reason*, volume 3. MIT press.

- SMBT (2009). Conchyliculture et pêche lagunaire. Technical report.
- SMBT (2012). SCOT: bilan de concertation. Technical report, Syndicat Mixte du Bassin de Thau.
- SMBT, Ifremer, BRL, and Eau, E. (2009). Omega Thau - Phase 1 Etape 1. Technical report, SMBT - Ifremer - BRL - Egis Eau, Sète.
- SMBT, Ifremer, BRL, and Eau, E. (2010). OmegaThau - Phase 1 Etape 4 : Rapport de synthèse. Technical report, SMBT - Ifremer - BRL - Egis Eau.
- Snedden, G. A., Cable, J. E., and Kjerfve, B. (2012). Estuarine geomorphology and coastal hydrology. In Day, J. W. J., Crump, B. C., Kemp, W. M., and Yanez-Arancibia, A., editors, *Estuarine Ecology*, chapter 2, pages 41–62. Wiley-Blackwell, Hoboken, New Jersey, second edition.
- Standing, A. (2008). Corruption and industrial fishing in Africa. Technical report, Anti-corruption resources center, Bergen, Norway.
- Star, S. and Griesemer, J. (1989). Institutional ecology, translations' and boundary objects: Amateurs and professionals in Berkeley's Museum of Vertebrate Zoology, 1907-39. *Social studies of science*.
- Steffen, W., Richardson, K., Rockström, J., Cornell, S. E., Fetzer, I., Bennett, E. M., Biggs, R., Carpenter, S. R., de Vries, W., de Wit, C. A., Folke, C., Gerten, D., Heinke, J., Mace, G. M., Persson, L. M., Ramanathan, V., Reyers, B., and Sörlin, S. (2015). Planetary Boundaries: guiding human development on a changing planet. *Science (New York, N.Y.)*, 348(6240):1–17.
- Thiele, J. C. and Grimm, V. (2010). Netlogo meets r: Linking agent-based models with a toolbox for their analysis. *Environmental Modelling & Software*, 25(8):972–974.
- Tissot, C., Brosset, D., Barillé, L., and Grel, L. L. (2012). Modeling Oyster Farming Activities in Coastal Areas: A Generic Framework and Preliminary Application to a Case Study. *Coastal management*, (September):37–41.
- Treuil, J.-P., Drogoul, A., and Zucker, J.-D. (2008). *Modélisation et simulation à base d'agents: exemples commentés, outils informatiques et questions théoriques*. Dunod.
- Trivers, R. (2006). Reciprocal altruism: 30 years later. In *Cooperation in primates and humans*, pages 67–83. Springer.
- Tversky, A. and Kahneman, D. (1974). Judgment under uncertainty: Heuristics and biases. *Science*, 185(4157):1124–1131.

- Valdez Domingos, F. X., Azevedo, M., Silva, M. D., Randi, M. a. F., Freire, C. a., Silva de Assis, H. C., and Oliveira Ribeiro, C. a. (2007). Multi-biomarker assessment of three Brazilian estuaries using oysters as bioindicators. *Environmental Research*, 105(3):350–363.
- Vasilakopoulos, P., Maravelias, C. D., and Tserpes, G. (2014). The alarming decline of mediterranean fish stocks. *Current Biology*, 24(14):1643–1648.
- Villena, M. G. and Zecchetto, F. (2010). Subject-Specific Performance Information can Worsen the Tragedy of the Commons: Experimental Evidence. *SSRN Electronic Journal*.
- Vogt, J. M., Epstein, G. B., Mincey, S. K., Fischer, B. C., and Mccord, P. (2015). Putting the " E " in SES : unpacking the ecology in the Ostrom social- ecological system framework. *Ecology and Society*, 20(20):1.
- WFD (2012). Report from the Commission to the European Parliament and the Council on the Implementation of the Water Framework Directive (2000/60/EC) River Basin Management Plans. Technical report, European Commission (COM), Brussels.
- White, I. (2001). Safeguarding environmental conditions for oyster cultivation in New South Wales. Technical Report August, NSW Healthy Rivers Commission.
- Whittington, R. J., Dhand, N. K., Evans, O., and Paul-Pont, I. (2015). Further observations on the influence of husbandry practices on OsHV-1 μ Var mortality in Pacific oysters *Crassostrea gigas*: Age, cultivation structures and growing height. *Aquaculture*, 438:82–97.
- Wickham, H. (2009). *ggplot2: elegant graphics for data analysis*. Springer New York.
- Wickham, H. (2014). *tidyr: Easily Tidy Data with spread() and gather() Functions*. R package version 0.2.0.
- Wickham, H. and Francois, R. (2015). *dplyr: A Grammar of Data Manipulation*. R package version 0.4.2.
- Wilensky, U. (1997). Netlogo segregation model (evanston, ill.: Center for connected learning and computer-based modeling, northwestern university).
- Wilkinson, L. (2006). *The grammar of graphics*. Springer Science & Business Media.
- Wilson, J. G. and Fleeger, J. W. (2014). Estuarine benthos. In Day, J. W. J., Crump, B. C., Kemp, W. M., and Yanez-Arancibia, A., editors, *Estuarine Ecology*, chapter 12, pages 1–3. Wiley-Blackwell, Hoboken, New Jersey, second edition.

- Worm, B., Hilborn, R., Baum, J., Branch, T. A., Collie, J. S., Costello, C., Fogarty, M. J., Fulton, E. A., Hutchings, J. A., Jennings, S., Jensen, O. P., Lotze, H. K., Mace, P. M., McClanahan, T. R., Minto, C., Palumbi, S. R., Parma, A. M., Ricard, D., Rosenberg, A. A., Watson, R., and Zeller, D. (2009). Rebuilding global fisheries. *Science (New York, N.Y.)*, 325(5940):578–585.
- Young, O. R., Berkhout, F., Gallopin, G. C., Janssen, M. a., Ostrom, E., and van der Leeuw, S. (2006). The globalization of socio-ecological systems: An agenda for scientific research. *Global Environmental Change*, 16(3):304–316.
- Zorpas, A. (2010). Environmental management systems as sustainable tools in the way of life for the SMEs and VSMEs. *Bioresource technology*, 101(6):1544–57.

Contents (detailed)

List of Figures	v
List of Tables	vii
Acronyms	ix
Remerciements	xi
Résumé en Français	xiii
0.1 Introduction	xiii
0.2 Etat de l'art	xiv
0.2.1 Gestion de ressources naturelles et communs	xiv
0.2.2 Menaces	xvi
0.2.3 Information et partage de l'information	xvii
0.3 Methodologie	xix
0.4 Etude de cas	xx
0.4.1 Généralités et intérêt du cas de l'ostréiculture	xx
0.4.2 Cas spécifiques et artéfacts focaux	xxii
0.5 Résultats	xxiv
0.5.1 Une menace publique : la microbiologie	xxiv
0.5.2 Une menace privée : l'herpès virus OsHV-1	xxvi
0.6 Discussion	xxviii
0.6.1 Sur l'approche méthodologique	xxix
0.6.2 Sur le concept de menaces	xxx
0.6.3 Sur l'information pour la gestion de ressources naturelles	xxx
0.7 Conclusion	xxxi
1 Introduction	1
1.1 Natural resources management	1
1.2 Information and information sharing	2
1.3 Purpose and problem of the thesis	3
1.4 Structure of the thesis	4
1.5 A tale in the thesis	5

I	State of the Art	9
2	Resources, Dilemmas and SES	11
2.1	Resources and users	12
2.1.1	Goods and resources	12
2.1.2	Users and property rights	13
2.2	Social dilemmas	14
2.2.1	Social dilemmas and what to do about them	15
2.2.2	Common-pool resources management design principles	17
2.2.3	Asymmetric commons	18
2.3	SES framework	19
2.4	Conclusion	22
3	Threats for Goods	23
3.1	Why a threat?	23
3.1.1	A definition of threats	24
3.1.2	Risk, uncertainty et al.	26
3.1.3	Design principles seen as answers to threats	28
3.1.4	Some examples and solutions	28
3.1.5	Conclusion on threat definition	31
3.2	Typology of threats	32
3.2.1	Properties	32
3.2.2	Typology	35
3.2.3	Goods and threats	36
3.3	Adding threats to the SES framework	36
3.3.1	No threats in the SES framework	36
3.3.2	Threats in the robustness framework	39
3.3.3	Adding threats	39
3.4	Conclusion	40
4	Information Sharing for NRM	43
4.1	More information on information	43
4.1.1	Information in various contexts	44
4.1.2	Information as a good	47
4.2	Local challenges	48
4.2.1	Intrinsic challenges for artifacts	49
4.2.2	Without forgetting networks	51
4.3	Why, what and how?	51
4.3.1	Why share information in NRM?	52
4.3.2	Information? What kind of information?	53
4.3.3	How to share information?	53
4.3.4	Conclusion on why, what and how	54
4.4	Local IS artifacts	55
4.4.1	Description	55

<i>CONTENTS (DETAILED)</i>	249
----------------------------	-----

4.4.2 Evaluation	56
4.5 IS stakes for threats	57
4.5.1 Public threat	57
4.5.2 Private threat	58
4.5.3 Common threat	58
4.6 IS for NRM in the literature	59
4.7 Conclusion	61

Conclusion	63
-------------------	-----------

II Methodology	67
-----------------------	-----------

Introduction	69
---------------------	-----------

5 Methodology for Case Studies	71
---------------------------------------	-----------

5.1 Case choice	71
5.2 Interviews and participatory observation	72
5.2.1 Thau Lagoon	72
5.2.2 New South Wales, Australia	75
5.2.3 Thau Lagoon, again	78
5.3 Conclusion	78

6 Agent-Based Modeling	81
-------------------------------	-----------

6.1 What is ABM?	82
6.1.1 “Micromotives and macrobehavior”	83
6.1.2 Advantages and limits of ABMs	85
6.2 Agents	86
6.3 ABM for NRM	88
6.4 The technical side of the ABM	88
6.4.1 Description tools	89
6.4.2 Simulation and analysis tools	92
6.5 Conclusion	94

III Case Studies	95
-------------------------	-----------

Introduction	97
---------------------	-----------

7 Estuaries, Oysters and Oyster Farming	99
--	-----------

7.1 Catchments and estuaries	100
7.1.1 Estuaries	100
7.1.2 Catchments	102
7.1.3 Water quality	102
7.1.4 Users of estuaries	103

7.1.5	Catchment and estuaries in short	104
7.2	Oysters	105
7.2.1	Biology of oysters	105
7.2.2	Ecology of oysters	106
7.2.3	Oysters as bioindicators	107
7.3	Oyster farming	108
7.3.1	Practices	108
7.3.2	On the difficulties to farm oysters	109
7.4	The SES as a choice	110
7.5	Conclusion	112
8	Two Cases - SES Analysis	113
8.1	New South Wales, Australia	113
8.1.1	History, economy, geography	113
8.1.2	Settings and institutions	117
8.1.3	Studied information sharing artifacts	122
8.1.4	Conclusion - NSW	127
8.2	Thau Lagoon, France	127
8.2.1	History, economy, geography	128
8.2.2	Political setting and structured institutions	131
8.2.3	Studied information sharing artifacts	133
8.2.4	Conclusion - Thau Lagoon	136
8.3	Discussing the cases	140
8.4	Conclusion	141
9	Goods and threats for oyster farmers	143
9.1	Goods for oyster farmers	143
9.1.1	Goods and resource system	144
9.1.2	Common-pool resource principles	145
9.2	Threats for oyster farmers	146
9.2.1	Microbiology	147
9.2.2	Virus	148
9.3	Conclusion	150
	Conclusion	151
	IV Results	153
	Introduction	155
10	Information Sharing for Public Threats: Microbiology	157
10.1	Dealing with microbiological threat in NSW	158
10.1.1	Legitimization of stewardship over water management	158
10.1.2	Evaluation of consequences on the SES	161

<i>CONTENTS (DETAILED)</i>	251
10.1.3 Partial conclusion	161
10.2 Dealing with microbiological threat in Thau	163
10.2.1 A difference that makes a difference?	163
10.2.2 Partial conclusion	166
10.3 Discussing strategies	167
10.4 Conclusion	170
11 Information Sharing for Private Threats: Virus	171
11.1 Agent-based model description	172
11.1.1 Overview	172
11.1.2 Design concepts	175
11.1.3 Details	182
11.1.4 Submodels and parameters	182
11.2 Analysis	184
11.2.1 Oysters and environment	184
11.2.2 Oyster Farmers	190
11.2.3 Conclusion on results	197
11.3 Conclusion	198
V Discussion	201
12 Discussion	203
12.1 On the methodological approach	204
12.1.1 Case studies	204
12.1.2 SES framework	206
12.1.3 Agent-based modeling	207
12.2 On threats in SESs	211
12.2.1 Goods	211
12.2.2 Threats	212
12.3 On information sharing artifacts for NRM	214
12.3.1 Information sharing artifacts to face threats	215
12.3.2 General findings on information sharing artifacts	217
12.3.3 Information sharing artifacts for NRM	218
13 Conclusion	221
13.1 Findings	221
13.2 Future research	224
13.3 Epilogue	224
Bibliography	227
Contents (detailed)	247

VI Appendices	253
A ODD protocol detailed	255
B SES second-tier variables	259
C Environmental Information Sharing: a Means to Support the Legitimization of Oyster Farmers' Stewardship over Wa- ter Quality Management in NSW, Australia?	261

Part VI

Appendices



Appendix A

ODD protocol detailed

This appendix contains a detailed version of Table [6.1](#), p.[92](#) that contains a list of questions associated with each structural element. Those questions have driven the model development.

Table A.1: The ODD+D protocol (Müller et al., 2013)

Main block	Structural element	Guiding question
Overview	Purpose	What is the purpose of the study? For whom the model is designed?
	Entities, state variables and scales	What kind of entities are in the model? By what attributes (i.e. state variables and parameters) are these entities characterised? What are the exogenous factors / drivers of the model?
	Process overview and scheduling	What are the temporal and spatial resolutions and extents of the model? What entity does what and in what order?
Design concepts	Theoretical and empirical background	Which general concepts, theories or hypotheses are underlying the model's design at the system level or at the level(s) of the submodel(s) (apart from the decision model)? What is the link to complexity and the purpose of the model? On what assumptions is/are the agents' decision model(s) based? Why is/are certain decision model(s) chosen? If the model/submodel (e.g. the decision model) is based on empirical data, where do the data come from? At which level of aggregation were the data available?
	Individual decision-making	What are the subjects and objects of the decision-making? On which level of aggregation is decision-making modeled? Are multiple levels of decision making included? What is the basic rationality behind agent decision-making in the model? Do agents pursue an explicit objective or have other success criteria? How do agents make their decisions? Do the agents adapt their behavior to changing endogenous and exogenous state variables? And if yes, how? Do social norms or cultural values play a role in the decision-making process? Do spatial aspects play a role in the decision process?

Continued on next page ...

Table A.1 – continued from previous page

Main block	Structural element	Guiding question
Design concepts	Learning	Do temporal aspects play a role in the decision process?
		To which extent and how is uncertainty included in the agents' decision rules?
		Is individual learning included in the decision process? How do individuals change their decision rules over time as a consequence of their experience?
	Individual sensing	Is collective learning implemented in the model?
		What endogenous and exogenous state variables are individuals assumed to sense and consider in their decisions? Is the sensing process erroneous?
		What state variables of which other individuals can an individual perceive? Is the sensing process erroneous?
		What is the spatial scale of sensing?
	Individual prediction	Are the mechanisms by which agents obtain information modeled explicitly, or are individuals simply assumed to know these variables?
		Are the costs for cognition and the costs for gathering information explicitly included in the model?
		Which data do the agents use to predict future conditions?
		What internal models are agents assumed to use to estimate future conditions or consequences of their decisions?
	Interaction	Might agents be erroneous in the prediction process, and how is it implemented?
		Are interactions among agents and entities assumed as direct or indirect?
		On what do the interactions depend?
Collectives	Collectives	If the interactions involve communication, how are such communications represented?
		If a coordination network exists, how does it affect the agent behavior? Is the structure of the network imposed or emergent?
		Do the individuals form or belong to aggregations that affect and are affected by the individuals? Are these aggregations imposed by the modeler or do they emerge during the simulation?
		How are collectives represented?

Continued on next page ...

Table A.1 – continued from previous page

Main block	Structural element	Guiding question
Design concepts	Heterogeneity	Are the agents heterogeneous? If yes, which state variables and/or processes differ between the agents?
		Are the agents heterogeneous in their decision-making? If yes, which decision models or decision objects differ between the agents?
	Stochasticity	What processes (including initialization) are modeled by assuming they are random or partly random?
	Observation	What data are collected from the Agent-Based Modeling (ABM) for testing, understanding and analyzing it, and how and when are they collected? What key results, outputs or characteristics of the model are emerging from the individuals? (Emergence)
Details	Implementation details	How has the model been implemented? Is the model accessible, and if so, where?
	Initialization	What is the initial state of the model world, i.e. at time $t = 0$ of a simulation run? Is the initialization always the same, or is it allowed to vary among simulations? Are the initial values chosen arbitrarily or based on data?
	Input data	Does the model use input from external sources such as data files or other models to represent processes that change over time?
	Submodels	What, in detail, are the submodels that represent the processes listed in “Process overview and scheduling”?
		What are the model parameters, their dimensions and reference values? How were the submodels designed or chosen, and how were they parameterized and then tested?

Appendix B

SES second-tier variables

This appendix contains all second-tier variables of the [Social-Ecological System \(SES\)](#) framework as presented in [McGinnis and Ostrom \(2014\)](#).

<i>First-tier variable</i>	<i>Second-tier variables</i>
Social, economic, and political settings (S)	S1 - Economic development S2 - Demographic trends S3 - Political stability S4 - Other governance systems S5 - Markets S6 - Media organization S7 - Technology
Resource system (RS)	RS1 - Sector (e.g. water, forest, pasture, fish) RS2 - Clarity of system boundaries RS3 - Size of resource system RS4 - Human-constructed facilities RS5 - Productivity of system RS6 - Equilibrium properties RS7 - Predictability of system dynamics RS8 - Storage characteristics RS9 - Location
Governance systems (GS*)	GS1* - Policy area GS2* - Geographic scale of governance system GS3* - Population GS4* - Regime type GS5* - Rule-making organizations GS6* - Rules-in-use GS7* - Property-rights systems GS8* - Repertoire of norms and strategy GS9* - Network structure GS10* - Historical continuity
Resource units (RU)	RU1 - Resource unit mobility RU2 - Growth or replacement rate RU3 - Interaction among RU RU4 - Economic value RU5 - Number of units RU6 - Distinctive characteristics RU7 - Spatial and temporal distribution
Actors (A)	A1 - Number of relevant actors A2 - Socioeconomic attributes A3 - History or past experiences A4 - Location A5 - Leadership / Entrepreneurship A6 - Norms (trust/reciprocity) / Social capital A7 - Knowledge of SES / Mental models A8 - Importance of resource (dependence) A9 - Technologies available
Action situations: Interactions(I) → Outcomes (O)	I1 - Harvesting I2 - Information sharing I3 - Deliberation processes I4 - Conflicts I5 - Investment activities I6 - Lobbying activities I7 - Self-organizing activities I8 - Networking activities I9 - Monitoring activities I10 - Evaluative activities O1 - Social performance measures (efficiency, equity, accountability, sustainability) O2 - Ecological performance measures (overharvested, resilience, biodiversity, sustainability) O3 - Externalities to other SESs
Related ecosystems (ECO)	ECO1 - Climate patterns ECO2 - Pollution patterns ECO3 - Flows into and out of focal SES

Table B.1: First and second tier variables of a SES ([McGinnis and Ostrom, 2014](#)).

Appendix C

Environmental Information Sharing: a Means to Support the Legitimization of Oyster Farmers' Stewardship over Water Quality Management in NSW, Australia?

This paper is in press in *Natural Resources Forum*.

Environmental information sharing: a means to support the legitimization of oyster farmers' stewardship over water quality management in NSW, Australia?

Nicolas Paget, Katherine Anne Daniell, Ana Rubio Zuazo and Olivier Barreteau

Abstract

Oyster farmers depend on good water quality. Activities upstream from estuaries result in externalities that impact water quality. Over the last 10 years, oyster farmers have been developing estuary-wide environmental management systems (EMSs) to tackle internal (i.e. industry-related) and external (i.e. catchment) issues in New South Wales, Australia. Drawing on interview-based research and document analyses, this paper shows that the process of creating an EMS for the oyster industry, as well as the creation of the EMS itself, resulted in legitimizing the industry's stewardship over the natural resource it depends on (water). For the oyster industry, this result was due to a change in the scale on which EMSs have been developed: instead of viewing issues at the individual business level, the systems expanded their viewpoint to the entire catchment, and included every oyster business in the estuary, as well as all other activities in the upper catchment. By providing a means of communicating internal efforts and with the support of local government bodies, EMSs provided a mechanism with which influence over upstream actors and activities could be exerted. We demonstrate this by using the 'social-ecological systems' and 'ENCORE' frameworks, emphasizing the transitions that allowed for this change of scale to take place.

Keywords: Information sharing; natural resources management; social-ecological systems; oyster farming; environmental management systems.

1. Introduction

1.1. Estuarine health and water quality

Estuaries are confluences. They contain water originating both from catchment runoff and from the sea. For coastal estuaries, rainfall results in pollution inflows from the catchment via run-off into the waterways. These inflows

can contain a combination of chemical pollution from towns and roads, pesticides, fertilizers and animal manure from farms (diffuse pollution), and sewage overflows from towns or individual houses (point source pollution), as well as increased turbidity resulting from erosion and soil run-off. Salinity balance is also affected by the quantity of freshwater entering estuaries from tributaries or water treatment plant outfalls that is available to mix with sea water. Hence, water quality can be affected in many ways as a result of the introduction and balance of these elements in estuaries.

Estuarine health is therefore a good indicator of environmentally friendly activities in the catchment. Estuaries are mostly open environments that, except for specific locations like restricted areas of marine protected parks, can be used for professional or recreational fishing or for general leisure, such as boating or swimming. Estuaries can be channels through which trade boats pass. Estuaries, and more generally catchments, are thus social-ecological systems (Folke *et al.*, 2005; Ostrom *et al.*, 2007) in which actors or appropriators act, having different goals and concerns.

Estuarine health can be monitored and managed through a wide variety of water quality indicators (Fairweather, 1999). According to the Department of Environment and

Nicolas Paget is at the National Scientific Research Center (CNRS), Laboratory for systems analysis and decision Research Unit (LAMSAD) (CNRS), Paris, France and National Research Institute of Science and Technology for Environment and Agriculture (IRSTEA), Water Resource Management, Actors and Uses Joint Research Unit (UMR G-EAU), Montpellier, France. E-mail: nicolas.paget@irstea.fr

Katherine Anne Daniell is a Fellow at The Australian National University, Centre for European Studies, Acton, ACT, Australia. E-mail: katherine.daniell@anu.edu.au

Ana Rubio Zuazo is at Hornsby Shire Council, Natural Resources, 296 Peats Ferry Road, Hornsby, New South Wales, Australia. E-mail: ARubio@hornsby.nsw.gov.au

Olivier Barreteau is at National Research Institute of Science and Technology for Environment and Agriculture (IRSTEA), Water Resource Management, Actors and Uses Joint Research Unit (UMR G-EAU), Montpellier, France. E-mail: olivier.barreteau@irstea.fr

Conservation of New South Wales (NSW), Australia (NSWDEC, 2005), these indicators are developed based on five estuarine-related components: aquatic ecosystem health; primary (swimming) and secondary (boating, fishing) contact recreation; visual amenities; and aquatic commercial food production. A range of key variables can be found in the document (NSWDEC, 2005). For human activities, an indicator that is shared for all objectives is fecal coliforms (*E. coli*) levels. For aquatic ecosystem health, the main indicators are algae blooms (in particular toxic blooms) and the presence of high levels of nutrients in the water. In this paper, we will focus mostly on water quality related to human activities. In particular, we focus on levels of *E. coli* (cfu/100mL) in the water. Depending on the activity, sampling and thresholds are different. Table 1 presents the requirements for the most demanding activity: oyster farming (see following sections).

Water quality can be considered a public good (Ostrom *et al.*, 1994; Hess and Ostrom, 2003) since it is non-rivalrous and non-excludable. Every user or appropriator uses water as is. However, poor water quality has effects at different levels for various users, and good water quality is the desirable state. In light of the key role of estuarine water quality for some economic activities, we wonder

how local estuarine actors can gain legitimacy as stewards of a resource that is of core importance to them. We take oyster production as an emblematic estuarine use with a high sensitivity to water quality.

1.2. Information sharing to legitimize stewardship over water quality management

Information has been shown to be a component of an action situation within the institution analysis and development framework (Ostrom, 2009b). Research on global common goods has pointed out the fact that information can be considered to be a common good, emphasizing the difference between information, artifacts and facilities (Hess and Ostrom, 2003). Other research on information in the context of commons management has shown its importance, for instance through studies of the effects of information availability and granularity for conditional cooperation (Villena and Zecchetto, 2010; Janssen, 2013; Bell *et al.*, 2015). Information can be shared one-to-one (Bodin and Crona, 2009) or with groups of people during meetings or through information sharing artifacts (Allen and Kilvington, 2005; Pahl-Wostl, 2005). Information availability increases reflexivity, which has been proven to

Table 1. Sampling requirements for oyster farming in NSW

Seafood business section	Product to be tested	Variable to be quantified	Limit	Frequency of testing
Oyster grower	Cultivated oysters (in oyster lease)	Escherichia coli	<2.3 E. coli/g (direct harvest) <10 E. coli/g (restricted harvest)	After an event i.e., rainfall, sewer pollution, peak holidays (direct harvest areas) Every month (restricted harvest)
Oyster grower	Water from oyster harvest area (in lease)	Faecal coliforms	14 cfu/100 ml (direct harvest) 70 cfu/100 ml (restricted harvest)	As per above
Oyster grower	Phytoplankton (from waters close to harvest areas)	Harmful algal species	As per phytoplankton action Limit included in the Biotoxin Manual	Fortnight or during algal bloom present
Oyster grower	Cultivated oysters (in oyster lease)	Paralytic, diarrhetic and amnesic shellfish poisoning toxins (PSP, DSP and ASP)	Presence of biotoxins	Every fortnight if phytoplankton testing results positive
NSW food authority and oyster grower	Cultivated oysters (in oyster lease)	Heavy metals (arsenic, cadmium, lead, mercury, selenium, copper and zinc)	As per Australian National Food Authority Standards, e.g., Pb < 10 µg/g dry mass	Every 5 years
Seafood processor-offering ready-to-eat oysters	Opened oysters	Escherichia coli	Not exceeding 2.3/g	Every 20 batches
	Packed oysters	Escherichia coli	Not exceeding 2.3/g	Every 20 batches
	Cooked/smoked oysters	Listeria monocytogenes	Not detected in 1g	Every 10 batches
All oyster processors	Non-reticulated water used in connection with the production and processing of oysters	Escherichia coli	Not detected in 100ml	Not treated – every month Treated – every 6 months

All estuaries have the same threshold, even though the frequency of testing may vary, especially depending on local weather conditions.

be critical for social-ecological systems (Young *et al.*, 2006). Local and global environmental information systems have been developed in the context of raising environmental awareness (Haklay, 1999), and are known to help companies cope with internal and external pressures (El-Gayar and Fritz, 2006). To the best of our knowledge, their influence on collective environmental management, the focus of this paper, has never been studied. Is environmental information sharing a way to empower actors while ensuring the sustainability of a resource that is valuable to different users? Can information sharing fuel institutionalization processes?

In this paper, we investigate these questions by studying the case of oyster farmers in NSW, Australia. This population of actors that use estuaries as a resource is frequently impacted as the result of a number of upstream catchment activities. Estuarine health is needed for optimal oyster production. If an estuary is healthy, then oyster mortality levels are kept to a minimum and oyster growth and commercial harvest remain optimal most of the time, resulting in higher profitability. Recently, new management plans have been collectively written by oyster farmers in several estuaries where oysters are grown. We seek to explore how oyster farmers managed to gain legitimacy over water quality management and have become stewards of the resource they depend on.

Section 2 of the paper provides background information on the NSW case study, including the history of oyster farmer engagement in estuarine water quality management. Section 3 then presents the research methodology and frameworks used for analyzing the impact of environmental management systems (EMS) creation and use on the legitimization process of oyster farmers as water quality stewards. Section 4 follows with the results of this analysis; they are discussed in Section 5. Section 6 provides our conclusions.

2. Context

2.1. Oyster farming in NSW: a general overview

Commercial oyster farming is one of the oldest aquaculture activities in NSW, and started in the 1870s (OISAS, 2014). Oysters grow naturally in the shorelines of every estuary in NSW. Oysters are also grown commercially in 32 estuaries. In NSW, 43 estuaries are larger than 5 km²,¹ and 26 of these contain oyster farming activities. Oysters are a key-stone seafood product on the east coast of Australia, and generate a strong demand in the seafood market. Although production has been declining since mid-1980 due to major issues like diseases and water pollution, it is the most important commercial seafood industry in NSW (Schrobback *et al.*, 2014), with a production of 2,979

metric tons in 2011/12, or 32% of the state's total commercial fisheries production, valued at \$33 million, or \$35,000/ha, and directly employing 1,600 people, with 318 license holders (ABARE, 2014). Most businesses are family-owned medium size businesses (less than five people working), and a few are large companies. The NSW oyster production accounts for 38% of Australia's total oyster industry production value (ABARE, 2014).

Oysters are filter-feeder animals that have the capacity of filtering between 0.5 and 1 ml of water during their lifetimes (White, 2001). Oysters filter to extract phytoplankton and organic matter from the water column, thereby providing ecosystem services in estuaries as they play key roles in the uptake and recycling of nutrients, and coupling pelagic and benthic processes, all of which are related to water quality (Fulford *et al.*, 2010). As a result of the filtration activities, oysters store water in their guts for a few days before releasing it, filtered. Some of the particles present in the water column can be dangerous to human health and hence, oysters become unsuitable for human consumption. In most cases, these particles appear as a result of upstream anthropogenic activities. Consequently, the oyster industry suffers at the hands of others, i.e., polluting a public resource that is of core importance for oyster farmers. Oysters, like any filter-feeder, have been considered worldwide as good indicators of estuary health (Phillips, 1977; Phillips and Yim, 1981; Scott and Lawrence, 1982; Rosas *et al.*, 1983).

In NSW, three types of oysters are cultivated: the native Sydney Rock Oyster (SRO – 4,786,802 dozen in 2013/2014), *Saccostrea glomerata*, the Pacific Oyster (PO – 255,213 dozen), *Crassostrea gigas*, and marginally the Flat Oyster, *Ostrea angasi* (NSWDPI, 2014). Pacific Oysters are approved in seven estuaries, and in six are found under the form of sterile triploids since this species is considered a noxious fish (OISAS, 2014). Oysters can be naturally caught (\$1,401,343 worth); others are grown in hatcheries (\$421,728). Some oyster farmers grow oysters from spat to customer in a single location. Others are specialized in a specific age, and buy oysters from hatcheries or move oysters around according to which environment is best for the oyster at each specific moment of its life, so as to increase growth rates.

2.2. Water quality needs for the NSW oyster industry

Along the South Coast of NSW, the harvesting of oysters is forbidden when levels of *E. coli* reach 14 cfu/100 ml, swimming is forbidden when levels reach 150 cfu/100 ml and fishing is forbidden when levels are 1000 cfu/100 ml (NSWDEC, 2005). Even though these levels may vary depending on local conditions, they show that oyster farmers are the most sensitive users of estuary water. A minimum deterioration of water quality leads to pass the threshold for oyster harvesting. Oyster farmers' first interest is thus to maintain good water quality. It consequently

¹<http://www.environment.nsw.gov.au/estuaries/list.htm>

seems coherent to rely partly on oyster farmers' interest and local knowledge to assist in water quality management. They already participate and co-finance an intensive water quality monitoring programme managed by local authorities called the shellfish quality assurance programme. The cost for monitoring is shared equally by oyster farmers and the food authority through a shellfish quality assurance Programme (ASQAP, 2009). The programme involves intensive water and meat sampling and testing, with a particular importance placed on microbiological and algal/phytoplankton testing. It ensures optimal food safety, dealing with consequences of poor water quality. See Table 1 for details of these requirements. The collective cost for oyster farmers in the Lower Hawkesbury (5 harvest areas, 2 phytoplankton sites, 15 water sites, 12 oyster sampling sites) is around AU \$40,000 per year.

If these levels are reached, production estuaries are closed following procedures, negotiated between the NSW Food Authority and oyster farmers. These procedures differ slightly in different localities. After a period of time determined by the procedure, the estuary, or parts of the estuary if a zoning system is implemented, is reopened for harvesting. Table 2 shows different causes for closure in the Shoalhaven estuary.

Oyster farmers mainly undertake the sampling, and the testing is conducted in NATA-certified laboratories. According to protocol, closures are imposed by the NSW Food Authority. Part of the measures is linked to automatic closures after rainfall, since rain triggers an increase in *E. coli* levels. Protocol is updated annually based on results from the programme, including knowledge evolution. For example, in the Wonboyn estuary, the closing trigger dropped from 25 ml of rain in 48 hours to 25 ml of rain in 24 hours (interview with oyster farmer, November, 2014). The NSW Food Authority also manages the reopening of harvest zones when *E. coli* levels drop back to acceptable levels. Each estuary has a growers association in which water monitoring is discussed along with other topics, a levy voted on and representatives elected every year.

Depending on the level of *E. coli* found year round in an estuary, harvest areas are classified at several levels. These levels are adjusted every year. The levels are categorized in order from best to worst water quality (Food Standards Code and the Food Regulation, 2010). In approved harvest

areas, growers are allowed to harvest and sell oysters directly from the harvest area except in adverse conditions (e.g. heavy rain) – not exceeding 14 cfu/100 ml of *E. coli*. In restricted harvest areas, growers are allowed to sell oysters after oysters are depurated in UV-treated water for 36 hours – not exceeding 70 cfu/100 ml of *E. coli*. Approved harvest areas have optimal estuary conditions for oyster production, as growers do not need to take depuration time into consideration prior to market.

Water quality is heavily impacted by catchment activities and is monitored mainly for the sake of consumer safety, and indirectly for oyster 'image.' Public health concerns and potential deaths can cause significant harm to the oyster image in the public eye, as was the case during the tragic Wallis Lake event in 1977, in which a number of people were infected with Hepatitis A as a result of consuming contaminated raw oysters (Conaty *et al.*, 2000). This event led to the creation of the Shellfish Committee in the NSW Food Authority (interview with Shellfish Programme manager, November, 2014).

Recently, several changes have taken place in the oyster industry that have led to a number of legal documents highlighting the industry's roles in the waterways, as well as the roles of catchment stakeholders to ensure long-term sustainability of the NSW oyster industry. Figure 1 represents the oyster farmers' representations of the system in which they were acting prior to these changes.

2.3. Recent processes

2.3.1. Emergence of a series of key oyster industry institutions

Institutions are being developed in an ad hoc manner with neither defined structures nor distinguishable goals. These institutions are nested, and tackle issues at different levels: estuary, several estuaries, coastal region, and state. At the estuary level, there are associations of producers, such as the Broken Bay Oysters Association (all oyster farmers from the Hawkesbury estuary). At this level, these institutions address local issues. In some cases, the institution does not do much. On a larger scale, the Sapphire Coast Wilderness Oysters (SCWO), an association created in 2011 and comprised of 19 oyster farmers from four nearby

Table 2. Closures in days for 2006–2012 in the Shoalhaven estuary

Closure reason (days)	2006	2007	2008	2009	2010	2011	2012	Grand total
Rainfall	29	78	29	13	98	48	49	344
Sewage discharge		47					13	60
Rainfall and sewage discharge						23		23
Precautionary closure		10			1			11
Toxic harmful algal bloom	10							10
Salinity below trigger level						7		7
Microbiological exceedance in water and/or shellfish			8	7		4		19
Grand total	39	135	37	20	99	82	62	474

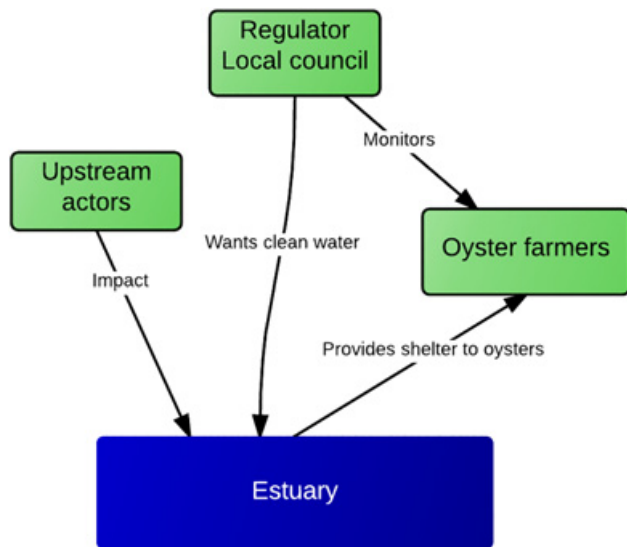


Figure 1. Oyster farmers' representations of the system prior to EMS implementation.

estuaries within the local government Bega Valley Region, is a voice for oyster farmers in the estuaries of the Sapphire Coast. This level is consistent with areas of local government, since the estuaries participating in the SCWO are those located within the Bega Valley Shire Council. At an even larger scale, the Australia's Oyster Coast (AOC), an association created in 2012 and comprised of 39 oyster farmers, covers the entire South Coast. These associations are working toward new oyster branding and marketing strategies, addressing local issues, affecting estuaries and members, and crafting rules or strategies for members, basing their argumentation on environmental responsibility. The Sapphire Coast Wilderness Oysters is represented in councils and workshops.

At the state level, the NSW Farmers' Association, the general farmers lobby in NSW, has an oyster committee represented by nine oyster farmers who look after the interests of oyster farmers on a state-wide level, i.e., all along the NSW coast. This association is required for the farming industry to speak with one voice. Government agencies know who to contact if they need to discuss issues with the industry. As a result of their expertise, oyster farmers can assist with the writing of better policies, obtain legal advice, and formulate plans (interview with oyster farmer member of the oyster committee, December, 2014). The NSW Farmers' Association is a great supporter of EMS development, and was consulted during the development of the Oyster Industry Sustainable Aquaculture Strategy (OISAS) (communication in workshop, November, 2014).

Most of these institutions are recent. What enabled their creation and development? In the following subsection, we show that environmental information sharing document creation was a key point in this process.

2.3.2. New information sharing documents

Two types of documents have emerged in the last 10 years. The first is a document written by the Department of Primary Industries (DPI) of NSW in 2006 and updated in 2014: the aforementioned OISAS. The second is a set of documents that have been written for the oyster industry at the estuary level: the aforementioned EMS.

The Oyster Industry Sustainable Aquaculture (OISAS) has been written and updated by the DPI, with support from the NSW oyster aquaculture industry. It "arose from concerns (...) as to the existing and potential impact on the oyster aquaculture industry associated with the rapid development of the NSW coastline" (OISAS, 2014). It states that "the maintenance of existing water quality, tidal range and flow will be achieved primarily through establishing links between the requirements for the sustainable cultivation of healthy oysters and catchment land and water use planning" (OISAS, 2014). The document also declares that for any development application, which could have an impact on water quality, oyster farmers must be consulted, and it lists elements that could help protect harvesting areas (OISAS, 2014). After nine years of existence, this document is now part of normal procedures for local councils during urban or industrial development application processes. Knowledge of OISAS varies from oyster farmer to oyster farmer, some "not even knowing of its existence" and others capable of "citing parts of the document" (interview with the author, November, 2014).

The second class of documents, the EMSs, is described as "a voluntary, industry driven, environmental initiative" (EMS Wagonga, 2012). They have been developed under the direction of an environmental non-governmental organization called OceanWatch Australia and local natural resource management agencies like the South Coast Catchment Management Authority. These documents are all publicly available on-line. The first one of these was developed for the oyster industry in the Broken Bay area in 2005. This was the Hawkesbury estuary that in 2004 had been wiped out by QX disease, killing nearly 100% of the local oysters (Butt and Raftos, 2007). Out of 32 estuaries producing oysters in NSW at the time this article was written, 17 have developed an EMS. The number of estuaries willing to develop an EMS is growing constantly (interview with EMS facilitator, November, 2014). A notable exception is Wallis Lake, the biggest oyster producer in NSW (OISAS, 2014), as growers in this estuary have business plans set using old infrastructure that is not the most environmentally-friendly technology.

All EMSs have the same layout and are adapted to each estuary to address local issues. The EMS documents contain a scope, an overview of the estuary, a list of best practices used in the estuary, a summary of the impacts from the industry's practices and external impacts affecting the industry. The document also has a risk assessment that scores the severity of the impacts, both internal and

external, toward optimal estuarine environmental conditions. Following the risk assessment, actions to be undertaken by the industry are proposed to mitigate each risk, including indicators to monitor the evolution of these risks and actions. The risks are evaluated at the estuary level and not on a business scale, creating solidarity among actors. Estuary-wide environmental management systems were developed through a series of meetings with all local growers, in which all local problems were raised and assessed.

Internal problems are those that could be tackled within the oyster industry. Projects are mostly funded by oyster farmers, partially helped by government grants that triggered the evolution process. Examples of typical projects are: moving to recyclable plastic cultivation infrastructure instead of tar-coated infrastructure, cleaning up derelict cultivation structures, and investing in more efficient engines.

External risks are those occurring outside the oyster farms such as: leachate of on-site sewage treatment systems or destruction of riparian habitats as a result of cattle intrusion to these areas. The EMS documents allow information sharing about the actions undertaken by oyster farmers and make their requirements legitimate to ensure profitability within their industry. Estuary-wide environmental management systems further generate feedback to upstream actors through information sharing.

On the south coast of NSW, two EMS officers have been nominated to be in charge of monitoring EMS implementation processes and representing oyster farmers in different councils and authority bodies. These officers help maintain the momentum of the EMS project, advocate for oyster farmers' interests and are contacted when development applications are submitted.

Thanks to these documents, the institutions that were created are becoming legitimate in the eyes of the councils and government authorities with whom they communicate.

3. Methods

3.1. Research approach

To study the effect that information sharing documents have on actors' abilities to manage their resources and foster institution creation, we adopted a case-based approach. To gather data and evidence, we interviewed 13 oyster farmers across NSW estuaries (Figure 2), and used a participant observation position in meetings.

The chosen case is a positive example of how some actors managed to impact and steward the quality of water, a public good on which they heavily depend, through the creation of new institutions made possible thanks to an environmental information sharing process. As described in Section 2, oysters are commercially grown in 32 estuaries in NSW, with 17 of them having developed estuary-wide

EMSs, a process started in 2005 and continuing today. To understand the effects of the EMS development process, we conducted a series of interviews with industry members and key oyster stakeholder representatives, attended oyster farmers' meetings and drew upon the deep knowledge of one of the authors of this paper, who has been working closely with the Australian oyster farming industry for more than 10 years. We analyzed the evolution of situations using the social-ecological systems (SES) (Ostrom, 2009a; McGinnis and Ostrom, 2014) and ENCORE (Ferrand, 2004; Daniell, 2012) (see Section 3.3) frameworks. The SES framework is used to take a large, specified collection of system components into account, as well as understanding their role in the system's governance. ENCORE is used to assess impacts resulting from the introduction of the EMS, not only on its intended effects on resources, but also on other dimensions related to the various components of the SES, including social ones.

3.2. Data collection

In November 2014, two of the authors interviewed 13 oyster farmers across six estuaries (79 licenses in these estuaries) out the 17 equipped with EMSs, five of which were located in the South Coast, and the last of which was located in the North Coast. The 13 oyster farmers interviewed included three growers in Wagonga Inlet, three in Merimbula Lake, two in Broken Bay (North Coast), and one each in Shoalhaven River, Pambula Lake, Wapengo Lagoon, and Nelson and Wonboyn Rivers. Some of the growers interviewed are proactive growers, keen on playing a leadership role in the industry. Among those, some are very involved in environment protection matters, such as the Bega Valley EMS officer or the one who implemented an EMS at the individual farm level. These growers played a significant role in the adoption of EMSs involving all farmers in each estuary. Other growers were randomly chosen.

The interviews were semi-structured, and supported by a set of pre-defined questions. The questions chosen were then adapted to the situation and discourse of the oyster farmer. Interviews usually lasted for around one hour, and all were recorded and transcribed. The questionnaire is available as an appendix of this paper, and was globally organized around three main topics. The first part was intended to gather data about local practices, as well as the oyster farmer's personal history. The second part investigated issues faced by farmers, both personally and at the estuary level. Lastly, the interview focused on collective action, with a particular emphasis on information and information sharing artifacts, especially EMSs, and the changes they fostered.

In addition to the above, we interviewed three actors involved in the industry: the EMS facilitator, the Shellfish programme manager of the NSW Food Authority and the author of the OISAS document, member of the NSW

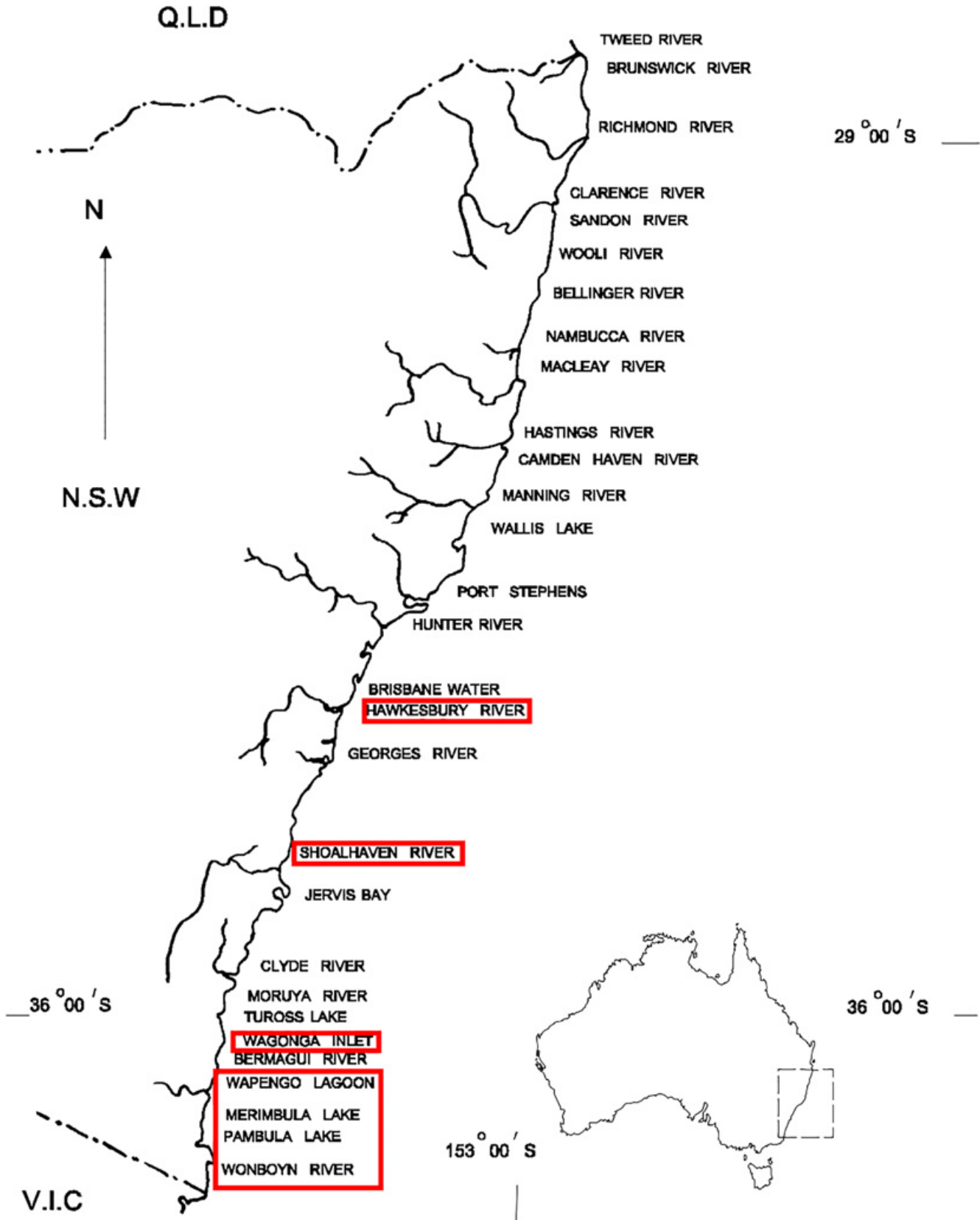


Figure 2. Main oyster producing estuaries in NSW. Visited estuaries are in boxes.
Source: Adapted from OISAS (2014).

Department of Primary Industries. Questions were adapted to the respondent. The interviews were similarly recorded and transcribed. These interviews were first based on understanding the role of the institutions for which they worked, as well as their personal involvement, and second on the role of information sharing in the industry.

We also attended a workshop called “The role of natural resources management in the NSW oyster industry,” held in Sydney in November 2014, which brought together six oyster farmers, seven public servants and a few other participants, such as a member of the NSW Farmers’ Association. They discussed the roles of each party openly, confronting positive and negative experiences, and what should be done next. The idea behind this arena was that “by sharing knowledge and information, and improving communication across stakeholders, [it] will help foster stronger partnerships and projects that deliver better outcomes for industry and the environment.”

The ideas of this paper were presented to the people who were interviewed for validation and completion feedback. The 6 out of 13 who responded agreed on the analysis developed, either accepting it as a whole or adding clarifications and precisions that we have subsequently included in our analysis and discussion.

3.3. Analysis frameworks

3.3.1. Social-ecological systems (SES)

We use a systemic perspective with the SES framework (Ostrom, 2009a; McGinnis and Ostrom, 2014; see Figure 3). It allows a thorough description of a system in which some actors interact with a (or several) renewable natural resource(s). In a SES, several entities that can be

described separately are linked together to form a complex system. The main categories are the resource system (RS), the resource units (RU), the actors (A) and the government system (GS*). A selection of relevant variables to our case has been made, and can be found in Table 4.

Resource systems can be seen as two nested systems, the smaller one being the estuary scale and the bigger one being the catchment scale. We will investigate the change in perspective that these documents create. Resource units are oysters, but they can include fish. At the estuary level, actors are oyster farmers, fishers, and boat users. At the catchment level, actors are farmers, homeowners, and the general community. The governance system is evolving, and it principally consists of catchment management authorities and local government agencies (i.e., councils) at the waterway-catchment level, the Food Authority and Department of Primary Industry at the state level, and new associations/institutions on the industry side.

3.3.2. ENCORE

ENCORE is an observation and evaluation model for participatory management processes (Ferrand, 2004; Daniell, 2012). It is an acronym of the following terms: *External* – improvement in the water management situation; *Normative* – norms, values and preferences of water users; *Cognitive* – representations and beliefs of users; *Operational* – practices and actions of users; *Relational* – social relationships among users; *Equity* – perception of social justice.

The definitions have been adapted from Daniell (2012) to fit the situation studied in this paper. It is a useful framework to list possible evolutions linked to a process involving a number of different actors.

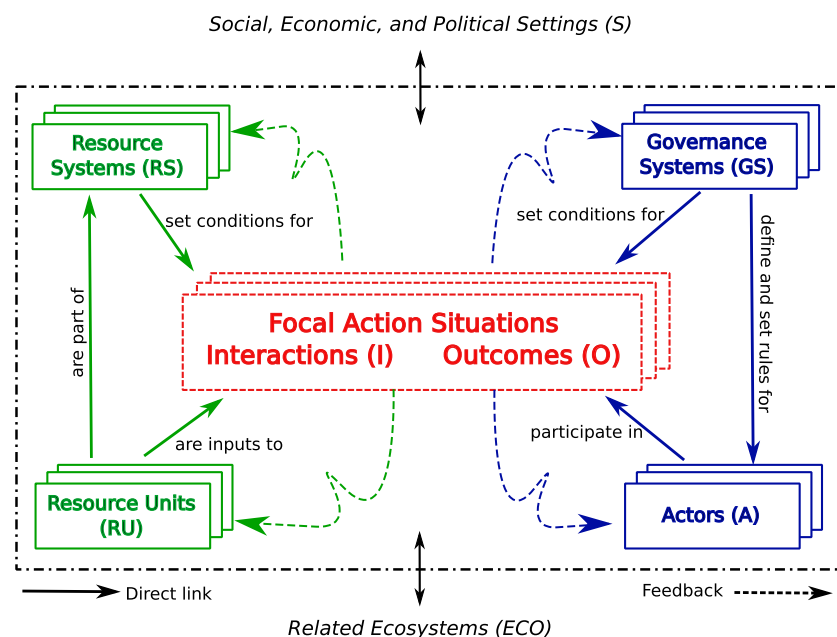


Figure 3. The social-ecological framework (McGinnis and Ostrom, 2014).

3.3.3. Framework completion

The frameworks were completed using the information gathered during the field investigation led by one of the authors and reviewed by another author, who has been an important actor in the NSW oyster farming industry for the past 10 years.

4. Results

This section first focuses on the originality of the EMS documents in the context of the case study: the EMSs are designed at the estuary level and not at the farm level. Then the analysis draws upon the SES and ENCORE frameworks to show that environmental information sharing can be a way to legitimize actors as stewards of their resources, as well as to foster institution creation.

4.1. Estuary-wide EMSs, an innovative approach to oyster farming

First, let us focus on fundamental changes that occurred on rules (GS6*) with a document that affected a great number of variables in the SES. Usually, EMSs are the “part of the global management system which includes the organizational structure, the planning activities, the responsibilities, the practices, the procedures, the processes and the resources necessary for development, implementation, achievement, evaluation and sustention of the environment policy” (Cotoc *et al.*, 2013: 1317). They help to “protect valuable environmental assets, manage local areas on the most suitable way and develop relationships between people and the natural environment” (Mangra *et al.*, 2014: 1). They are organization-oriented: “an EMS has the primary purpose of preventing negative effects on the environment and improving a firm’s environmental practices” (Massoud *et al.*, 2011: 6). EMSs could be taken to meet a certification standard or could be left as codes of practice. Two standards for certification exist: the ISO 14001 international standard and the CE regulation 1221/2009n environment and audit management (Cotoc *et al.*, 2013). Literature shows that EMS implementation has positive outcomes for clients, costs (sparing unnecessary waste) and image (Massoud *et al.*, 2011; Psomas *et al.*, 2011; Ronnenberg *et al.*, 2011; Cotoc *et al.*, 2013), that several strategies can be followed (Nishitani, 2010) and that small businesses have many more difficulties in EMS implementation, despite achieving positive outcomes (Hillary, 2004; Collins *et al.*, 2007; Zorpas, 2010).

There is an important difference in the way EMSs have been conceived in the case study. The innovation lies in the creation of estuary-wide EMSs for the oyster industry. These EMSs involve a great majority of the businesses in an estuary, since most impacts and risks from and to the industry are equally shared by every business within a

waterway. To our knowledge, apart from those written for oyster farming, only a few EMSs have been designed for some fisheries at a general level in Australia, and these are not publicly available. The EMSs follow most ISO 14001:2004 standards, even though they are ‘not fully compliant’ (EMS Wagonga, 2012). It is seen as a code of practice that can be upgraded to ISO certification with minimum work. This will happen in the near future once the industry is ready to be audited. EMSs set global objectives for the industry as a whole, covering internal issues that maximize industry practices to minimum environmental impact and external issues that try to mitigate risks resulting from catchment users and processes. A few oyster farmers created EMSs for their own individual businesses, but they offered limited benefits (interview with one of such oyster farmers, November, 2014). Since the main objective for the oyster industry is water quality improvement, it can only be reached through collective action. The developed internal indicators are aggregations. For instance, in the category ‘Ecological effects’, the indicator ‘Number of derelict leases rehabilitated’ ensures monitoring of the sub-objective “work with NSW DPI and other organizations to identify and rehabilitate derelict leases” (EMS Wagonga, 2012).

Estuary-wide environmental management systems can thus serve as collective action documents, or documents that make every member of a category of actors in an SES responsible for management, going beyond simple, albeit laudable, business-oriented EMSs. They can be part of sustainable management of a shared resource. This makes even more sense, considering the recognized difficulty in EMS implementation for small businesses (Zorpas, 2010).

4.2. Evolution of oyster farmers’ roles – legitimization and feedback through an information and environment-centered boundary object

4.2.1. Legitimation

Internal change in rules led to better internal and external information sharing (I2) through a legitimization of oyster farmers who provide stewardship over the water quality process. As emphasized in Section 1, to ensure good water quality, oyster farmers have to cope with other actors’ actions, and have to deal with upstream catchment users and processes (i.e. external risks). There were also misunderstandings throughout the community regarding oyster farmers’ impacts on the estuary. The development of EMSs allowed communities to learn about typical industry practices, as well as industry’s roles as stewards of good water quality. They are information-laden documents. Using the ENCORE framework, Table 3 shows their impacts on different populations. All the listed changes did not occur in all estuaries where EMSs were developed (see Section 5.1. on limitations). An EMS is a long and comprehensive document, containing information that can be irrelevant to a

Table 3. Possible evolution of actors according to ENCORE dimensions (see Section 3.3. for definitions)

Dimension	Potential impact of EMS and OISAS implementation on different actors	
External	Oyster farmers	Cleaning up of derelict and polluting infrastructure, investment in sustainable infrastructure
	Govt. and councils	Can use oyster farmers' knowledge and presence to assist when monitoring
	Farmers	Fencing off cattle to limit access to the estuarine foreshore, regrowth of riparian vegetation
	House owners	Better on-site sewage system
Normative	Community	Safety during swimming and recreational fishing
	Oyster farmers	OF should provide stewardship over water, others should be made aware of their impacts
	Govt. and councils	OF should provide help as stewards of the waterways
	Farmers	Need to play a role in keeping good water quality
Cognitive	House owners	Should be made aware that they can have an impact on water quality
	Community	Should be made aware that they can have an impact on water quality
	Oyster farmers	Government is not an enemy
	Govt. and councils	Oysters are good indicators of estuarine health
Operational	Farmers	Farming activities can impact water quality
	House owners	Micro behaviors can affect the whole system
	Community	Aware that OF are not harmful (if not beneficial) to the environment, oyster farming is associated with clean environments, suitable for tourism, and generating income for the local economy
	Oyster farmers	Reducing high internal risks by implementing risk mitigation procedures
Relational	Govt. and councils	Oyster farmers are integrated in decision processes
	Farmers	Maintain cattle out of the water, behind fences
	House owners	Improve or maintain sewage treatment
	Oyster farmers	Legitimate members of the community, can talk to others with pride
Equity	Govt. and councils	OF are knowledgeable partners
	Farmers	OF are partners in environment quality
	House owners	Accept better OF requests for improvements
	Community	Common interest in tourism
Equity	Oyster farmers	Feel that they have input
	Govt. and councils	Better acceptance of decisions
	Farmers	Agree to invest knowing OFs make efforts
	House owners	Agree to invest knowing OFs make efforts
	Community	Legitimate use of crown resource

broad audience. It is updated on a regular basis, in general every five years, and thus does not contain situation evolutions between those dates. Two other documents can be considered as parts of the EMS, even though they are not the EMS per se.

The first of these two other documents is an annual review, publicly available, stating the evolution of the situation and the actions undertaken since the last review (I10). It was created using a collective summary of the actions undertaken by all oyster farmers. The second one is a small leaflet of general and concise information, informative enough for the general public, highlighting what has been achieved in recent years. Having all these different roles of information sharing, management helping and procedure

facilitating, EMSs can be considered as boundary objects, or "objects that are both adaptable to different viewpoints and robust enough to maintain identity across them" (Star and Griesemer, 1989: 387). They are information systems that allow communication among different categories of actors at the required level.

According to Gietzelt *et al.*, 2014, p.2: "When South East LLS first engaged with the oyster industry in 2003, (oyster farmers) were frustrated with their lack of influence over processes and practices threatening their industry. When issues (...) caused the temporary closure of oyster harvesting, their response was generally reactionary, and they did not have a loud and collective voice when expressing their concerns to government and the community."

Table 4. Evaluation of consequences of the implementation of the environmental information sharing system – only the relevant variables have been selected from McGinnis and Ostrom (2014)

Variable (see Figure 3)	Initial features	Transition	Features after implementation
RS3 - Size of resource system	Estuary	External issues internalized	Catchment
RS7 - Predictability of system dynamics	Difficult to predict	Indicators multiplied	More precise: growth and mortality
GS2 – Non government organization	Almost none	Emerged through meetings	SCWO, AOC
GS3 – Network structure	Porous	Meetings	Very dense, at least at the estuary level
A6a – Trust/Reciprocity	Little	Meetings	Improved, for environment at least
A7 – Knowledge of SES/Mental models	Upstream actors responsible	Holistic view	Part of a catchment
A9 – Technology available	Any	Long-term thinking while elaborating	Sustainable, non-polluting (internally)
I2 – Information sharing	Little	Forced through meetings on consensual subjects	Among actors, with others
I3 – Deliberation process	Meetings for water quality	Canalized through meetings	Regular meetings at several levels
I5 – Investment activities	Water and meat monitoring	Identified through meetings	New technologies (individually), clean-up
I6 – Lobbying activities	Dispersed	Made easier with hard documents	More centralized
I8 – Networking activities	Dispersed	Hard documents exist, EMS officer	More systematic (incl. in government processes)
I9 – Monitoring activities	Water and meat	Government implicated	Extensive, partnership with government for stewardship, growth and mortality
I10 – Evaluative activities	Little	Range of indicators defined	Extensive
O1 – Social measures	Little	Deep thinking about sustainability	Sustainability is core
O2 – Ecological performance measures	Little	Deep thinking about sustainability	Precisely defined
ECO2 – Pollution patters	Many, upstream, dispersed	Scale change	Now internal and more reachable
ECO3 – Flows into and out of focal SES	Flow from catchment	Scale change	Now internal and more reachable

Following this, OISAS explains to what extent local councils and the oyster industry worked hand in hand to develop EMSs and address issues raised, to the point of creating an Oyster Partnership Programme in 2006, which partly subsidizes an EMS implementation officer position and promotes oyster performance monitoring programmes (RS7, I9, O2), among other actions (Gietzelt *et al.*, 2014). Furthermore, as explained in OISAS, 2014, upon submission of a development application to a Council, consequences on water quality are to be considered and oyster farmer representatives consulted in case of possible impact (I10, O2). This communication provides a discussion among key stakeholders (interview with oyster farmer, November, 2014).

4.2.2. Evaluation of consequences on the SES

The identification of boundaries and content of the SES by its actors has dramatically changed with the creation of these documents (see Section 3.3). Estuary-wide environmental management systems are new resources available to oyster farmers to act on an object of core importance to them: water quality and the estuary in general. As shown before, they are used in many different ways: during development application processes; for raising awareness; to

allow farmers to voice their views; and for interacting with councils. Oyster industry sustainable aquaculture is another government-owned resource that can be used in similar cases to ensure optimal water quality. The SES framework analysis shows in Table 4 that these new resources have had an effect on a considerable number of variables of the SES. One of the most important is that it allowed the size of the system (RS2) for the oyster farmers to be redefined. Instead of being focused and constraining actions to the estuary limit, the system now includes the whole catchment and the processes that could indirectly affect oyster farming practices. This had an impact on pollution patterns (ECO2) and flows into and out of focal SES (ECO3): pollution events are now internal, and thus can more easily be addressed, and flows in and out are reduced because the system is defined at the catchment level, which prevents water from entering from other systems, except the sea. This could happen thanks to the definition of new rules at all levels: constitutional, collective and operational (GS*). Estuary-wide environmental management systems are all the more efficient as they are emerging following most of the core principles of common-pool resource management (Ostrom, 1990), helped by a cooperative attitude of government bodies. These rules have affected information sharing, self-organizing, monitoring, networking and evaluative

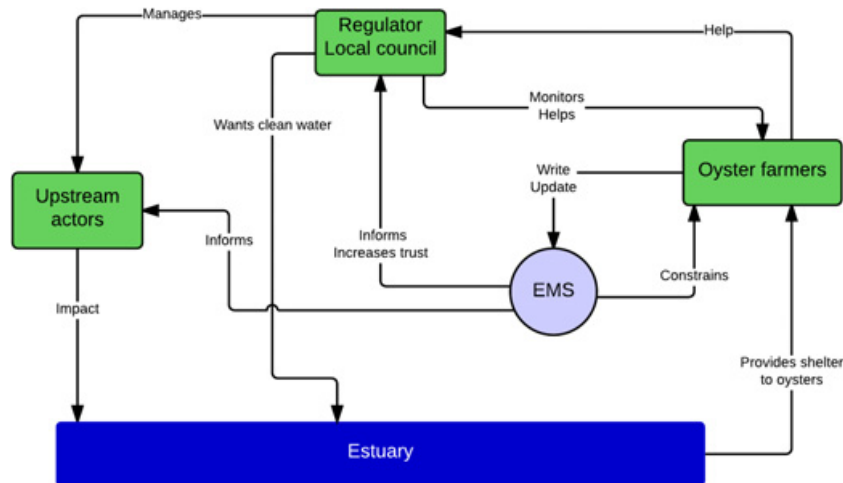


Figure 4. Oyster farmers' representation of the system after EMS implementation.

activities. They even defined social and ecological performance measures that will allow efficient monitoring of outcomes. Figure 4 shows the evolution of oyster farmers' representation of the system (A7).

5. Discussion

This case study focuses on NSW oyster farmers who have developed environmental management systems to increase their ability to mitigate risks by increasing dialog with upstream and public actors. This approach has positively impacted the industry. There is more cohesion among actors, a change in SES view, and a reinforcement of legitimacy over use and management of the resources they both use and share. The process seems to be an effective solution for enhancing or strengthening links among industry members and catchment actors.

5.1. Limitations

Some limitations exist, and these were pinpointed during interviews. First, launching the environmental information sharing process in itself can be tough, in that it is adversely affected by internal conflicts and beliefs of actors, preventing further institutionalization. Then, despite having achieved the process and building of institutions, some areas have been wiped out due to environmental factors, thus demonstrating that this process does not guarantee complete sustainability and resilience within the industry. Finally, the support of public institutions plays a critical role, either favoring or not favoring a change in actors' roles.

The first difficulty lies in process initialization. In Australia, the first oyster farming EMS was developed in Tasmania, in 2005. The EMS's benefits were advocated by a proactive oyster farmer. According to the EMS facilitator, these processes could only emerge through another oyster farmer's advocacy. Even at the local scale within each

estuary, a local champion needs to be identified, so that he or she drives the process of creating an EMS for the whole industry. This champion's opinion can lead to the success or the failure of the EMS implementation (interview with EMS facilitator, November, 2014). The success in developing and implementing EMSs in other estuaries and the availability to access government grants to implement EMSs' actions is now a motivation for other estuaries to develop their own EMS. The process is much easier when council or catchment management authority personnel are involved (interviews with oyster farmers, November, 2014), as it means that these regulatory bodies have similar goals to those of industry members.

Adoption and understanding of EMS advantages is progressive. It is an opt-in document. According to the EMS facilitator, it is becoming the norm in estuary management: not having an EMS could leave oyster farmers behind, in particular missing out on the option of having a voice in catchment issues or obtaining grants that require the development of EMSs. This issue could be resolved with time.

It was mentioned in Section 2.3.2 that the process of implementing EMSs enhanced communication among oyster farmers. This fostered institution creation and elevated water management as a common issue. However, it did not prevent other issues from arising. Beliefs of actors can prevent appropriation of a subject that is of general interest. In Wapengo Lake, even though an EMS was developed in 2010 (EMS Wapengo, 2010), some growers applied for Pacific Oyster (PO) cultivation approval. Since diploid PO is considered a pest in NSW, it is forbidden to be cultivated in NSW estuaries except in Port Stephens (OISAS, 2014). If approved, the cultivation of triploid PO is allowed; however, some actors believe that growing triploid PO could be harmful to the estuary and SRO performance as a result of exceeding the carrying capacity of the estuary. Trials of PO cultivation led to the creation of rifts among oyster farmers in that locality, to the point that communication among farmers is currently non-existent.

An EMS document cannot cover everything. Monitoring and developments must be periodically updated. Although evaluation for industry-wide EMSs does not yet exist, identification of issues affecting water quality or other environmental topics and the implementation of strategies and actions to tackle them, both internally and externally, is a positive process, as shown in Section 4.1. EMSs do not prevent all risks. A group of Lower Hawkesbury estuary farmers, one of the largest groups of oyster producers in NSW, was the first oyster group to have implemented an EMS in NSW. They created an association (Broken Bay Oysters) in 2005, and implemented and enacted the first EMS that same year. At the time, only two estuaries had developed EMSs. They implemented most of the EMS actions and the water quality was optimal for oyster farming (interview with BBO president, October, 2014). After being wiped out in 2004 by QX Disease, the industry recovered during the 2005–2011 period, swapping production from the SRO, a native oyster species, to the PO (EMSBBBO, 2011). In January 2013, this estuary got hit again by the Pacific Oyster Mortality Syndrome, a virus that killed nearly 100% of Pacific oysters in the Hawkesbury. By 2014, only three oyster farmers remained in the estuary. Water quality results are very good, and almost all internal risks were addressed at that time, as described in the EMS (EMSBBBO, 2011). However, despite growers being key pioneers in the EMS process and implementation, major unexpected events outweighed the benefits of implementing EMSs.

The Lower Hawkesbury River catchment was the first to implement an estuary-wide EMS in 2005. This effort was very much supported by the local council, the Hornsby Shire Council. This effort was translated financially through support for the cleaning of derelict and tarred infrastructure. It is also visible through investments made in water monitoring: six telemetry-based monitoring stations in the river, in addition to an extensive water quality monitoring programme that is regularly undertaken by council and the oyster farmers. Pollution levels and early warning alerts are shared between both bodies. The mutual help that oyster farmers and the council can give each other has been officially recognized through a memorandum of understanding, signed in 2011 between the Broken Bay Oyster Association and the Hornsby Shire Council. The South Coast Local Land Services (LLS) in Nowra, Batemans Bay and Bega work closely with oyster farmers, supporting their efforts and recognizing their roles in estuary management. The South Coast LLS states that: “EMS is not only the tool that identifies best practice management within the industry, but is also a foundation for growers and South East LLS to actively engage other industries, stakeholders, government agencies, landholders and local communities on catchment issues that impact on oyster production and estuary health” (Gietzelt *et al.*, 2014: 1).

In the North, there were some issues that prevented a similar level of improvement as along the South Coast.

First, catchment management agencies were less proactive because of a lack of resources. Second, key environmental issues, such as acid sulfate soils (ASS), existed. These affect the oyster industry as well as other industries, such as recreational fishers and land-based farmers. These issues are both hard to manage and have significant impacts on the industry and waterways. In some cases, ASS are located on private land, leading to difficulties in finding a public means of mitigating the issues, or the work requires extensive financing and operations. Slowly, however, some estuaries are succeeding in employing competent research groups. Third, growers were less proactive in EMS development, making it harder for councils and other groups to support the process. This confirms the demonstration of this publication: if an industry has an EMS, then there is a professional commitment by the industry to do the right thing, and other stakeholders might subsequently consider assisting in ‘external’ catchment issues.

5.2. Information sharing: a prelude to institutionalization

As downstream actors located at the very end of physical flows of catchment areas in estuaries, oyster farmers have to deal with externalities resulting from other actors. They are in competition with other actors for the use of their most important resource, the estuary (under the form of Crown Land in NSW) and its corresponding water quality. The EMS implementation process enabled them to create a feedback loop, which consists of information flow as shown in Figure 5.

The study shows that while implementing such documents is not a smooth process since it can be impeded by strong beliefs or lack of initial support by actors or the public sector, or even be limited in effect by unforeseen risks, it does create important positive effects. First, local cohesion and communication are enhanced. These effects have been witnessed in the case developed in this paper, and could probably be achieved through different kinds of projects involving local actors, since these projects could foster regular meetings, and thus discussions, among themselves. The advantage of this project over other types of projects could be the needed thinking and formalization of water and the estuary as shared resources, as well as joint responsibilities. Second, working on projects like these, being exposed to opinions of others allows participants to build a greater understanding of their own environments, as demonstrated by the change in views of the SES. One could think of further strengthening

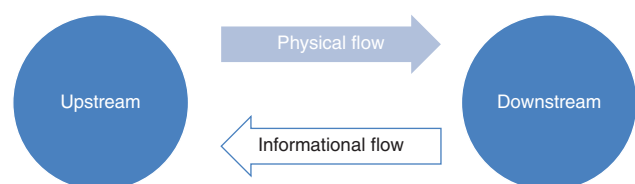


Figure 5. Physical vs. informational flows.

impacts by implicating upstream actors, or other users of the estuary, in a bigger project. This kind of idea has been applied by the Hornsby Shire Council when developing their estuary management plan (HSC *et al.*, 2008; Daniell, 2012).

To our knowledge, this case is a unique case of actors developing EMSs, especially in a voluntary way. To our knowledge, it does not exist elsewhere in Australia in any industry. It could be interesting to try to apply this process with other types of actors that are located at the end of a chain, such as beekeepers. Like oysters, bees are important for the environment, oysters by filtering water, bees by pollinating crops, and are indicators of healthy and sustainable practices, having to undergo upstream actors' externalities as well.

The mere existence of these documents is not a solution in itself. However, it is a good step toward legitimization of core actors over a shared resource. Demonstrating personal and institutional environmental responsibility through well-built, transparent and accessible information sharing documents can be an efficient way of improving work with other actors.

6. Conclusion

The goal of the study was to explore possible consequences of environmental information sharing over the stewardship of a shared resource that is of core importance to some actors. These actors, in this case oyster farmers, managed to implement documents that led to more cohesion amongst themselves, as well as to more negotiating power with other actors and local public authorities.

Despite some limits, environmental monitoring, information production and sharing can have multiple positive effects on water quality, estuary management, maintenance of resource system productivity, and local actors. Different users or managers of the estuary can unite to ensure good water quality. In this case, changing the scale of the problem is part of the solution. And in the case of NSW oyster farmers, this process came from two different sides.

First, the government officially acknowledged the role that oyster farmers needed to play in using best practices to ensure minimum impact on the estuarine environment, recognizing them as environmental stewards, since oysters are extremely sensitive to water quality. Second, in many estuaries, EMS documents emerged. These documents, crafted by oyster farmers, stated they have a responsibility in maintaining good water quality and identifying their own internal responsibilities and external risks, which are mainly upstream responsibilities of other actors. These documents proved to everyone (councils, governments, community) that oyster growers were responsible, and thus legitimated their role in estuary/catchment management. Thus, they were able to effectively act at the level of the whole catchment instead of being limited to the estuary,

and hence to address other actors' actions that were affecting them. This enabled the creation of practical feedback on the right level.

Perceptions, values and actions of different actors, as well as their views of each other, are therefore shifting. Oyster farmers took advantage of increasing environmental awareness in communities, and positioned themselves as guardians of the environment, being able to act to protect a public resource that is a condition for their industry. The industry is getting stronger, as attested by institution creation, despite significant setbacks caused by disease in some estuaries.

The EMS creation process will not always be successful. It needs to be internal, and can be hampered by unconvinced local actors, or slowed down due to formalizing internal issues or beliefs in a public document. New issues can arise as well, such as unforeseen new risks, resistance on the part of upstream actors, government passivity or support for other activities. These documents are a step toward sustainability of a trade, as well as a positive way to manage a natural resource by building trust in the possibility of collective action and improvement of practices of all, both within and outside of a trade. This paper adds to the global discussion on environmental management information systems by extending the domain in which they can be useful from single companies or farms to emergent collective action aimed at collective resource management.

Publicly shared information, whether in an extensive form such as an EMS or a more compact one such as a leaflet about the environment and actions demystifies, justifies, clarifies and legitimizes actors in a local environment.

References

- ABARE, 2014. *Australian Fisheries and Aquaculture Statistics 2013*. Australian Bureau of Agricultural and Resource Economics and Sciences (ABARES), Canberra. Available at http://data.daff.gov.au/data/warehouse/9aam/afstad9aamd003/2013/AustFishAquac-Stats_2013_v1.2.0.pdf (accessed 15 May 2015).
- Allen, W., Kilvington, M., 2005. Getting technical information into watershed decision-making. In: Hatfield, J.L. (Ed.), *The Farmers' Decision: Balancing Economic Successful Agriculture Production with Environmental Quality*. Soil and Water Conservation Society. pp. 45–61. Available at [http://pacificwater.org/userfiles/file/IWRM/Toolboxes/information management/AllenKilvington2005.pdf](http://pacificwater.org/userfiles/file/IWRM/Toolboxes/information%20management/AllenKilvington2005.pdf) (accessed 10 October 2014).
- ASQAP, 2009. Shellfish quality assurance program – operations manual. Available at http://www.pir.sa.gov.au/__data/assets/pdf_file/0006/120948/ASQAP_Manual_2009-01_091102.pdf. (accessed 10 November 2015)
- Bell, A.R., Shah, M.A.A., Anwar, A., Ringler, C., 2015. What role can information play in improved equity in Pakistan's irrigation system? Evidence from an experimental game in Punjab. *Ecology and Society*, 20(1): 51.
- Bodin, Ö., Crona, B.I., 2009. The role of social networks in natural resource governance: What relational patterns make a difference? *Global Environmental Change*, 19(3): 366–374.

- Butt, D., Raftos, D., 2007. Immunosuppression in Sydney rock oysters (*Saccostrea glomerata*) and QX disease in the Hawkesbury River, Sydney. *Marine and Freshwater Research*, 58(2): 213–221.
- Collins, E., Lawrence, S., Pavlovich, K., Ryan, C., 2007. Business networks and the uptake of sustainability practices: The case of New Zealand. *Journal of Cleaner Production*, 15(8-9): 729–740.
- Conaty, S., Bird, P., Bell, G., Kraa, E., Grohmann, G., McNulty, J.M., 2000. Hepatitis A in New South Wales, Australia from consumption of oysters: The first reported outbreak. *Epidemiology and Infection*, 124(1): 121–130.
- Cotoc, E.A., Traistaru, A., Stoica, A., 2013. Systems of environmental management. *European Journal of Humanities and Social Sciences*, 25(1): 1316–1325.
- Daniell, K.A., 2012. *Co-engineering and Participatory Water Management: Organisational Challenges for Water Governance*. Cambridge University Press, Cambridge.
- El-Gayar, O., Fritz, B.D., 2006. Environmental management information systems (EMIS) for sustainable development: A conceptual overview. *Communications of the Association for Information Systems*, 17(1): 756–784.
- EMS BBO, 2011. Broken Bay Oysters Association Incorporated - EMS. Technical report. Available at: http://www.oceanwatch.org.au/wp-content/uploads/2015/11/2011_03-Hawkesbury-EMS-5th-Edition.pdf (accessed 15 October 2014).
- EMS Wapengo, 2010. Wapengo Lake oyster growers-EMS Technical report. Available at: http://www.southcoasttoysterindustry.com.au/uploads/1/8/2/8/18287089/ems_wapengo_lake-feb2010.pdf (accessed 15 October 2014).
- EMS Wagonga, 2012. Wagonga Inlet oyster farmers-EMS. Available at http://www.oceanwatch.org.au/wp-content/uploads/2014/11/Wagonga-EMS-2012_10_23.pdf. (accessed 15 October 2014)
- Fairweather, P.G., 1999. Determining the “health” of estuaries: Priorities for ecological research. *Austral Ecology*, 24(4): 441–451.
- Ferrand, N., 2004. ‘ENCORE’ Un modèle d’analyse, ‘Intervention et Questions’ from an unpublished report, Cemagref (as published by Cambridge University Press), Montpellier, France.
- Folke, C., Hahn, T., Olsson, P., Norberg, J., 2005. Adaptive governance of social-ecological systems. *Annual Review of Environment and Resources*, 30(1): 441–473.
- Food Standards Code and the Food Regulation, 2010. NSW shellfish industry manual. Available at http://www.foodauthority.nsw.gov.au/_Documents/industry_pdf/NSW_Shellfish_Industry_Manual.pdf. (accessed 21 January 2015).
- Fulford, R.S., Breitburg, D.L., Luckenbach, M., Newell, R.I., 2010. Evaluating ecosystem response to oyster restoration and nutrient load reduction with a multispecies bioenergetics model. *Ecological Applications*, 20(4): 915–934.
- Gietzelt, A., Keating, J., Davies, H., 2014. Oysters: An aphrodisiac for engaging industry and coastal communities in sustainable estuary management. Coastal Conference, Ulla Dulla, 1–14.
- Haklay, M., 1999. From environmental information systems to environmental informatics-evolution and meaning. Working Paper Series 7. UCL Centre for Advanced Spatial Analysis, London.
- Hess, C., Ostrom, E., 2003. Ideas, artifacts, and facilities: Information as a common-pool resource. *Law and Contemporary Problems*, 66. Available at <http://scholarship.law.duke.edu/cgi/viewcontent.cgi?article=1959&context=lcip> (accessed 11 February 2013).
- Hillary, R., 2004. Environmental management systems and the smaller enterprise. *Journal of Cleaner Production*, 12(6): 561–569.
- HSC Haines, P., Fletcher, M., Rollason, V., Coad, P., 2008. Lower Hawkesbury Estuary Management Plan. Report prepared by BMT WBM Pty Ltd for Hornsby Shire Council.
- Janssen, M.A., 2013. The role of information in governing the commons: Experimental results. *Ecology and Society*, 18(4).
- Mangra, M.G., Cotoc, E.A., Traistaru, A., 2014. Sustainable economic development through environmental management systems. *Journal of Studies in Social Sciences*, 6(1): 1–14.
- Massoud, J.A., Daily, B.F., Bishop, J.W., 2011. Perceptions of environmental management systems. *Industrial Management & Data Systems*, 111(1): 5–19.
- McGinnis, M.D., Ostrom, E., 2014. Social-ecological system framework: Initial changes and continuing challenges. *Ecology and Society*, 19(2). Available at <http://www.ecologyandsociety.org/vol19/iss2/art30/> (accessed 5 October 2014).
- Nishitani, K., 2010. An empirical analysis of the effects on firms’ economic performance of implementing environmental management systems. *Environmental and Resource Economics*, 48(4): 569–586.
- NSWDEC, 2005. *Marine Water Quality Objectives for NSW Ocean Waters*. NSW Department of Environment and Conservation, Sydney. Available at <http://www.environment.nsw.gov.au/resources/water/mwqo/southcoast05582.pdf>. (accessed 20 January 2015).
- NSWDPI, 2014. *Aquaculture Production Report 2013–2014*. NSW Department of Primary Industries, Sydney. Available at http://www.dpi.nsw.gov.au/_data/assets/pdf_file/0019/543043/Aquaculture-Production-Report-2013-2014.pdf (accessed 20 January 2015).
- OISAS, 2014. NSW oyster industry sustainable aquaculture strategy second edition – 2014. Available at http://www.dpi.nsw.gov.au/_data/assets/pdf_file/0005/506939/oisas-second-edition-2014.pdf. (accessed 15 October 2014).
- Ostrom, E., 1990. *Governing the Commons: The Evolution of Institutions for Collective Action*. Cambridge University Press, Cambridge.
- Ostrom, E., 2009a. A general framework for analyzing sustainability of social-ecological systems. *Science (New York)*, 325(5939): 419–422.
- Ostrom, E., 2009b. *Understanding Institutional Diversity*. Princeton University Press, Princeton, NJ.
- Ostrom, E., Gardner, R., Walker, J., 1994. *Rules, Games, and Common-pool Resources*. University of Michigan Press, Ann Arbor, MI, USA.
- Ostrom, E., Janssen, M.A., Anderies, J.M., 2007. Going beyond panaceas. *Proceedings of the National Academy of Sciences of the United States of America*, 104(39): 15176–15178.
- Pahl-Wostl, C., 2005. Information, public empowerment, and the management of urban watersheds. *Environmental Modelling & Software*, 20(4): 457–467.
- Phillips, D.J.H., 1977. The use of biological indicator organisms to monitor trace metal pollution in marine and estuarine environments—a review. *Environmental Pollution (1970)*, 13(4): 281–317.
- Phillips, D.J.H., Yim, W.W.-S., 1981. A comparative evaluation of oysters, mussels and sediments as indicators of trace metals in Hong Kong waters. *Marine Ecology*, 6: 285–293.
- Psomas, E.L., Fotopoulos, C.V., Kafetzopoulos, D.P., 2011. Motives, difficulties and benefits in implementing the ISO 14001 Environmental Management System. *Management of Environmental Quality*, 22(4): 502–521.
- Ronnenberg, S.K., Graham, M.E., Mahmoodi, F., 2011. The important role of change management in environmental management system implementation. *International Journal of Operations & Production Management*, 31(6): 631–647.
- Rosas, I., Baez, A., Belmont, R., 1983. Oyster (*Crassostrea virginica*) as indicator of heavy metal pollution in some lagoons of the gulf of Mexico. *Water, Air, and Soil Pollution*, 20(2): 127–135.
- Schrobbach, P., Pascoe, S., Cogan, L., 2014. History, status and future of Australia’s native Sydney rock oyster industry. *Aquatic Living Resource*, 27(3-4): 153–165.
- Scott, G.I., Lawrence, D.R., 1982. The American oyster as a coastal zone pollution monitor: A pilot study 1. *Estuaries*, 5(1): 40–46.
- Star, S., Griesemer, J., 1989. Institutional ecology, translations’ and boundary objects: Amateurs and professionals in Berkeley’s Museum of Vertebrate Zoology, 1907–1939. *Social Studies of Science*. Available at <http://ss.sagepub.com/content/19/3/387.short> (accessed 11 February 2013).
- Villena, M.G., Zecchetto, F., 2010. Subject-specific performance information can worsen the Tragedy of the Commons: Experimental evidence. *SSRN Electronic Journal*. Available at <http://www.ssrn.com/abstract=1732862>. (accessed 30 October 2014).

- White, I., 2001. Safeguarding environmental conditions for oyster cultivation in New South Wales. Available at http://www.oysterinformationportal.net.au/wp-content/uploads/2012/03/White-2001-HealthyRiveComFinal_Report_Nov_2001.pdf. (accessed 25 October 2014)
- Young, O.R., Berkhout, F., Gallopin, G.C., Janssen, M.A., Ostrom, E., van der Leeuw, S., 2006. The globalization of socio-ecological systems: An agenda for scientific research. *Global Environmental Change*, 16(3): 304–316.
- Zorpas, A., 2010. Environmental management systems as sustainable tools in the way of life for the SMEs and VSMEs. *Bioresource Technology*, 101(6): 1544–1557.

Résumé

Nous explorons le lien entre partage d'information (PI) et gestion collective de ressources naturelles (GRN). La réflexivité est souvent considérée comme un moyen d'aide à la gestion et de mobilisation collective autour d'un objet commun. Cette réflexivité peut être atteinte grâce à la mise en place et à l'usage de systèmes de PI. Pour déterminer la relation entre PI et GRN, nous nous sommes intéressés au cas de l'ostréiculture. Les ostréiculteurs sont particulièrement sensibles à la qualité de l'eau et sont actuellement touchés par un virus virulent. Localement, ces acteurs ont développé et utilisent divers artefacts de PI. Ces artefacts sont en fait destinés à faire face à des menaces qui pourraient les toucher. L'identification de ce point fondamental a mené à développer le concept de menaces en utilisant la typologie traditionnelle de biens et ressources. Les menaces sont définies par le modèle <A,C,I,D,E>: un groupe d'acteurs (A) est inquiet pour certaines caractéristiques (C) de biens ou de ressources qu'ils utilisent influencées par l'infrastructure locale (I), les décisions d'acteurs (D) et les dynamiques environnementales (E). Elles sont organisées le long de deux axes: l'internalité, et l'exclusivité. Formuler la situation des ostréiculteurs en utilisant ce concept permet une caractérisation des enjeux pour les artefacts de PI pour la lutte contre les différents types de menaces.

Pour explorer ces enjeux, nous avons adopté une approche descriptive en se focalisant sur des artefacts réels et en évaluant qualitativement leur(s) impact(s) grâce au cadre ENCORE. Ensuite, nous avons développé un modèle à base d'agents pour évaluer différentes facettes des conséquences sur les SES. Les différents artefacts étudiés montrent qu'ils peuvent avoir des buts, médias et contenus variés peuvent améliorer la réflexivité, ou mener à peu, voire aucun changement. Ces améliorations sont intimement liées au processus de création de l'artefact.

Mots Clés

Partage de l'information
Gestion de ressources naturelles
Menaces
Simulation multi-agents
Cas d'étude
Ostréiculture

Abstract

This thesis aims at exploring the link between information sharing (IS) and collective natural resources management (NRM). Reflexivity is often referred to as a possible solution and one of the main ways to mobilize actors around collective objects. This reflexivity may be achieved through the implementation and use of IS artifacts. So as to qualify the relation linking IS and NRM, I focused on the case of oyster farmers (OF). OFs are sensitive to water quality and are currently severely harmed by a virulent virus. Locally, actors developed and used various types of IS artifacts. Artifacts are destined to tackle threats that OFs face. Realizing this focal point of interest led to develop the concept of threats using the traditional goods and resources typology as a base for comparison. Threats are defined as the <A; C; I; D; E> model: a group of actors A is concerned for some characteristics C of goods or resources they use which is influenced by local infrastructure I, human decisions D and environmental dynamics E. They are organized along two main axes: internality, that determines how open or closed the threat is, and excludability that focuses on how much actors may individually find ways to tackle the threat. Framing OF situation using this concept allows for a characterization of stakes for IS artifacts when they are destined to help actors cope with different types of threats, as actors of the cases do. To explore these stakes, I adopted a descriptive approach and first delved into actual artifacts, evaluating qualitatively their impact with the ENCORE framework. Then, I developed an exploratory ABM, to evaluate various facets of SESs. The various artifacts studied in the thesis show that their nature encompasses a wide variety of goals, contents or media, may lead to improvements in reflexivity or to little to no changes. These improvements are strongly linked to the artifact creation process.

Keywords

Information sharing
Natural Resources Management
Threats
Multi-agent simulation
Case studies
Oyster farming